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NORTHEASTERN REGION 25 Hz SYSTEM TEST

Report No 88-231-K

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ABSTRACT

Dynamic stability and motor starting tests were performed on the Northeastern 25 Hz system to assess the impact of the removal of the 115 kV interconnection to Hydro Quebec. The tests revealed that the interconnection has little effect on the system's dynamic stability and voltage support characteristics. The system exhibited positive damping of the prevalent low frequency mode of oscillation for each of the tested configurations. Voltage decline readings taken at various stations on the system, during the starting of the Kerr Addison mines hoist motor, were within acceptable limits under all tested conditions.

Detailed dynamic models of the Abitibi Canyon G1 excitation and governing systems are provided for use in digital planning and operating studies.

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To: Mr. B.C. Mitchell
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Dynamic stability and motor starting tests were performed on the Northeastern 25 Hz system to assess the impact of the removal of the 115 kV interconnection to Hydro Quebec. The tests revealed that the interconnection has little effect on the system's dynamic stability and voltage support characteristics. The system exhibited positive damping of the prevalent low frequency mode of oscillation for each of the tested configurations. Voltage decline readings taken at various stations on the system during the starting of the Kerr Addison mines hoist motor, were within acceptable limits under all tested conditions.

Detailed dynamic models of the Abitibi Canyon G1 excitation and governing systems are provided for use in digital planning and operating studies.

1.0 BACKGROUND

The Northeastern (NE) 25 Hz system is a relatively small system, with a connected capacity of less than 100 MVA (excluding customer generation and frequency changer capacity). The system is spread over a wide geographic area with over 600 kilometres of 115 kV circuit connecting the various industrial customers to the available generation. Currently there are two main interconnections: east of Kirkland Lake, 115 kV circuit K1Z is tied to the Hydro Quebec 25 Hz system at Provencher switching station, and at Martindale TS near Sudbury the 25 Hz system is connected to the Ontario Hydro 60 Hz system via three rotating frequency changers with a combined rating of 47 MVA. Figure 1 provides a simplified diagram of the NE 25 Hz system.

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According to current planning information, the interconnection to Hydro Quebec will be permanently disconnected in 1989. Loadflow studies conducted on the NE 25 Hz system without the interconnection to Hydro Quebec indicated that sufficient generating resources are available to supply the connected load [1]. However, on a number of occasions large power swings have been encountered on the NE 25 Hz system following loss of the interconnection to Hydro Quebec. Insufficient information was available from these incidents to permit detailed analysis of the system's behaviour. For this reason, a number of staged tests were planned to provide information on this system [1]. The tests were structured to meet the following objectives:

- monitor the dynamic stability of the system for a variety of operating configurations without the interconnection to Hydro Quebec.

- provide data to permit validation of computer models used to study the dynamic stability of the system.

The characteristics of the voltage regulator and governor on Abitibi Canyon G1 and the voltage regulator on Martindale FC1 were also studied through monitoring of certain key quantities and the performance of a few additional tests.

In addition to concerns related to the dynamic stability of the system, regional and operating groups expressed some misgivings regarding starting the 5000 HP hoist motor, located on the Kerr Addison mine site, without the interconnection to the Hydro Quebec System. In this configuration, Kerr Addison is supplied via a long (> 150 km) radial connection to the remainder of the system. Motor starting tests were performed to monitor voltage dips at Kerr Addison TS and at other points on the system for a variety of operating configurations.

Following extensive discussion with representatives from the various stakeholders (Transmission Operations Division, System Planning Division, Power System Operations Division and Northeastern Region) a series of staged tests were selected [2]. Some changes to this initial group of tests were required due to the unavailability of certain 25 Hz system elements on the test dates. In particular one of the small frequency changers at Martindale (FC6) was unavailable during the entire test period.

1.1 INSTRUMENTATION

To monitor the system's behaviour during both the dynamic stability and motor starting tests, instrumentation was placed at four key locations: Martindale TS/FC, Abitibi Canyon GS, Wawaitin GS and Kerr Addison TS. The quantities monitored at each location were agreed upon by the various stakeholder groups during the course of several planning meetings [1, 2]. Changes to the agreed upon list were made at the time of the tests due to the unavailability of current and potential transformers on certain system elements and at certain voltage levels.

The monitored items are listed below, grouped by station:

- Martindale TS/FC
  - 25 Hz, 13.8 kV FC1 terminal voltage
  - 25 Hz, total frequency changer real power output
  - 25 Hz, total frequency changer reactive power output
  - 25 Hz, system frequency monitored at the FC1 terminals (i.e. 13.8 kV level before step-up transformer)
  - 60 Hz, 13.8 kV FC1 terminal voltage
  - 60 Hz, FC1 reactive power output

It should be noted that on the 60 Hz side of the system at Martindale, the large frequency changer, FC1, is connected to the 115 kV system, while FC6 and FC7 are connected to the 44 kV system. This dictated the selection of the FC1 output for monitoring on the 60 Hz system.

- Abitibi Canyon GS (all quantities 25 Hz)
  - G1 13.8 kV terminal voltage
  - G1 real power output
  - G1 reactive power output
  - G1 field voltage
  - G1 wicket gate position

The last two items were included to permit monitoring of the activity, if any, of the G1 exciter and governor during both sets of tests.

- Wawaitin GS (all quantities 25 Hz)
  - "B1" bus 13.8 kV voltage
  - Total station real power output
  - Total station reactive power output

- Kerr Addison TS
  - "T1" bus 26.4 kV voltage

At both Wawaitin GS and Kerr Addison TS, PTs were not available at the 115 kV voltage level. During the motor starting tests an oscillograph was used at the Kerr Addison mine site to provide high speed records of the red and blue phase currents and the phase-to-phase motor terminal voltage (2300 V nominal).

At each location the transducer outputs were filtered and connected to multi-channel direct writing recorders. The selected filtering had negligible effect on the recorded magnitude and phase of oscillations occurring in the low frequency range of interest (i.e. below 0.5 Hz). The recorders at each of the locations were synchronized using common event-marker signals which were transmitted to the four stations via telephone voice circuits. The hardware, which was provided by Regional P&C staff, permitted aligning the time bases of the records collected at the four sites to within 100 to 200 ms.

2.0 DYNAMIC STABILITY TESTS

The staged dynamic stability tests were performed on Thursday, May 26, 1988. The tests consisted of initiating small disturbances on the system by rejecting one or two of the available four units at Wawaitin GS (two units rated at 3.75 MVA and two units rated at 2.5 MVA).

These units were selected for their modest size and because they provided a test disturbance which could easily be reproduced in computer simulations. The various configurations for which Wawaitin GS units were rejected are listed in Table 1 (Note - test numbers do not exactly correspond to those used in the system test plan [2]).

The chart records collected during each of the staged dynamic stability tests are attached as Figures 2 through 9.

Steady state levels for each of the monitored quantities are listed directly on each figure. Recorder speeds were set at 5 mm/s throughout the tests. Each record includes a mark on the time base indicating the exact instant that the Wawaitin unit(s) were rejected.

Prior to each test, Regional Operating staff took steady state meter readings of voltages and power flows at the following locations (refer to Figure 1):

- Lower Sturgeon GS
- Sandy Falls GS
- Hunta SS (power transfer from Abitibi Price Paper Company)
- Copper Cliff TS (power transfer from Inco)

The tabulated values for each test are included as Table 3.

The remainder of this section provides a discussion of the results obtained during the staged tests along with some observations on the system dynamics noted during the test period.

2.1 STAGED GENERATION REJECTION TESTS

Although a wide variety of responses were obtained for the tested configurations and operating conditions, the system exhibited positive damping of the low frequency mode of oscillation at all times. Comparison of the relative magnitude and damping of the oscillations for the various conditions provides an indication of the factors affecting the system-wide mode.

Comparison of Figures 2 and 3 indicates that the absence of the interconnection to Hydro Quebec (K1Z) has no measurable impact on the magnitude or damping of the 0.4 Hz mode. The contribution of the Abitibi Canyon unit to the low frequency swings is difficult to ascertain from either of these tests because of a higher frequency (approximately 1 Hz) component appearing in the unit output. A similar oscillation component is also apparent in the total station real power at Wawaitin GS. Since these machines do not have fast-responding automatic voltage regulators, these continuous oscillations are probably occurring at the natural frequency of the generator's torque-angle loop. Although these components are present under all conditions they are not of interest in considering the dynamic stability characteristics of the system.

2.1.1 Abitibi Canyon G1

Preliminary studies performed by the System Planning Division and the Power System Operations Division revealed that the operating mode of the Abitibi Canyon unit was a key factor in determining the relative damping of the low-frequency power swings through the Martindale frequency changers. Tests D2A, D2B and D2C (Figures 3, 4, 5 and 6) demonstrate the response of the system with the Canyon unit generating, condensing and off-line respectively. The worst condition, in terms of damping, is with the unit operating as a synchronous condenser. Using the generation rejection event markers provided on the records,

it is apparent that real power swings on the Abitibi Canyon unit are in phase with the swings in the power transfer through the frequency changers (i.e. a positive power swing out of Abitibi Canyon G1 produces a positive power swing into the 25 Hz side of the frequency changers). With the Canyon unit off-line, damping improves, although based only on this test it appears to be only marginally better than the results obtained for tests conducted with the unit generating real power. Monitoring of the system between staged tests revealed that the frequency changers' power transfer and terminal voltage are significantly less oscillatory when the Abitibi Canyon unit is off line. The measured frequency of oscillation is also dependent on the operating mode of the Canyon unit; the frequency of oscillation is between 0.36 and 0.4 Hz with the unit on-line (generating or condensing) and is around 0.48 Hz with the unit off line.

Since the oscillations at Martindale appear even when the Abitibi Canyon unit is disconnected from the system, other units (e.g. customer-owned units such as Island Falls GS) must be participating in this mode. From the collected records it appears that the output of the Wawaitin units, which remained on-line, did not oscillate significantly following each unit rejection.

2.1.2 Martindale Frequency Changers

The behaviour of the system with only the large frequency changer (FC1) on line was tested by rejecting a pair of units at Wawaitin with both FC6 and FC7 off line (Note - FC6 was off line during the entire test period). Comparison of Figures 7 and 8 (FC7 on line and off line respectively) indicates that damping is seriously degraded when the large frequency changer is operated alone. The frequency of oscillation is also lowered to approximately 0.36 Hz. Although the configuration was not tested, it seems logical to assume that if the Canyon unit had been operating as a synchronous condenser while the two small frequency changers were out of service, the damping of these oscillations would have been degraded further. For this reason, this operating configuration should be avoided if possible.

The effect of operating the system with only the two small frequency changers in service (i.e. FC1 off line) was not tested because of operating problems with the FC1 breakers which occurred during the scheduled test period. Preliminary simulations suggest that the system is dynamically unstable when operated in this configuration with the Canyon unit on line. Given the degradation in damping which was noted when both of the small frequency changers were off line it seems very likely that the system would exhibit negative damping if operated with FC1 (rating 33.5 MVA) off line, FC6 and FC7 (ratings 6.25 MVA and 6.75 MVA respectively) on line and the Abitibi Canyon unit generating or condensing. It is possible that this frequency changer configuration could be used during periods when the Abitibi Canyon unit is off line. Further digital simulations and field testing may be required to confirm the acceptability of this configuration.

2.1.3 Islanded Operation

The final staged dynamic test performed, involved opening breaker 19M1T at Timmins TS. In this configuration the system is separated into two halves, with the frequency changers connected to generation at Wawaitin GS, Sandy Falls GS and Lower Sturgeon GS and to Falconbridge TS and Copper Cliff TS (INCO). With circuit K1Z also open the remainder of the system operates as an island with Abitibi Canyon GS connected to a number of customers, including Abitibi Price Paper Company. Under steady state conditions the portion of the system connected to the frequency changers was well behaved. Following rejection of Wawaitin G1 the oscillations through the frequency changers (Figure 9) were similar in magnitude and damping to those which occurred with 19M1T closed and Canyon either off line or generating.

With 19MIT open, the measured oscillation frequency was higher, approaching 0.5 Hz. The results of this test support the opening of breaker 19M1T as a control action to eliminate persistent or growing oscillations appearing on the frequency changers at Martindale.

The portion of the system connected to Abitibi Canyon GS, operating as a small 25 Hz island, was subjected to constant low-magnitude oscillations at a frequency of approximately 0.08 Hz. Much larger swings at this very-low frequency mode also appeared during one of the motor starting tests (Test M-3) in which the frequency changers were separated from the system by opening breaker 10S1R at Copper Cliff TS. Eigenvalue analysis, performed by the Power System Operations Division predicted the appearance of this 0.08 Hz mode associated with the slow action of the Abitibi Canyon voltage regulator and governor. Figure 10 shows the activity of the Abitibi Canyon unit under steady state conditions with beaker 10S1R open. The turbine wicket gate oscillations confirm the involvement of the governor in this mode of oscillation. Although the field voltage also oscillates at 0.08 Hz, it is unlikely that this voltage regulator contributes to these swings due to the large voltage error deadband inherent in its design. Instead, these variations in field voltage are likely due to the effect of speed variations on the rotating pilot and main exciter outputs. The performance of the Abitibi Canyon G1 excitation and governing systems is discussed in more detail in Section 4. The performance of these systems and the dynamics of the associated low frequency mode will take on additional importance once K1Z is removed from service permanently, exposing the 25 Hz system to increased likelihood of islanded operation.

2.2 MONITORING DURING NORMAL OPERATION

In addition to the records obtained during the staged tests, continuous monitoring of the normal system dynamics was performed at various times during the test period. Additional records of interest, obtained in this manner, are attached as Figures 11 through 13.

Figure 11 illustrates the highly oscillatory behaviour of the system as measured at Martindale TS/FC one week prior to the staged tests. The exact time of this particular measurement was not recorded, however, the following operating information was obtained based on the approximate time:

- FC1, FC7 in service and delivering approximately 25 MW to the 60 Hz system.
- Interconnection K1Z to Hydro Quebec in service
- Abitibi Canyon G1 generating approximately 16 MW
- Wawaitin, Sandy Falls and Lower Sturgeon generating approximately 18 MW.

During the approximate period that these measurements were made, INCO (Copper Cliff TS) experienced a fault on one of their feeders resulting in their separation from the system. Power transfer to the Ontario Hydro network was approximately 6 MW prior to the fault. This is one possible explanation for the observed system behaviour, although undamped oscillations similar to Figure 11 were observed on several occasions during the setup period on May 19.

Although the system was generally well behaved during the day that the actual system tests were performed, oscillations occasionally occurred without any applied disturbance. Figure 12 is a measurement obtained following Test D4 which illustrates the highly oscillatory nature of the system when both of the small frequency changers are out of service at the same time. Figure 13 was recorded while Abitibi Canyon was generating (approximately 30 MW) and both FC1 and FC7 were in service. No staged test was performed when this measurement was made, however, the operators reported that INCO was hoisting during this period. Damping of the low frequency mode is relatively poor in this measurement when compared with staged test

records obtained for the same configuration and with the same loading of the Canyon G1 unit (e.g. Figure 7, test D3). Similar measurements were made during a period when the operators reported that the Abitibi Price Paper Company was varying its load and maneuvering Island Falls GS generation.

2.3 CONCLUSIONS ON DYNAMIC STABILITY TESTS

In general, the system behaved as predicted in the preliminary simulations performed by both the System Planning and Power System Operations Divisions using simplified representations of the NE 25 Hz system. During each of the staged tests the system exhibited positive damping of the low frequency oscillation mode. Damping of this mode does not appear to be significantly affected by the removal of the K1Z interconnection to Hydro Quebec. Damping is, however, a function of the operating mode of the Canyon G1 unit and the status of the frequency changers at Martindale. In terms of maximizing positive damping of the 0.4 Hz mode it would appear sensible to avoid extended outages of the small frequency changers at Martindale where possible. Stable operation of the system with only the two small frequency changers in service would probably only be possible during periods when the Abitibi Canyon unit is off line. Further simulations and field tests may be required to provide confirmation.

3.0 MOTOR STARTING TESTS - KERR ADDISON MINES

The Kerr Addison motor starting tests were performed on May 27, 1988. To establish a base case, against which other tests could be compared, the hoist motor was first started with the interconnection to Hydro Quebec in service. The motor was then stopped and re-started three times for various operating conditions with circuit K1Z out of service. Table 2 lists the statuses of the critical system components for each of the tests and Table 3 lists the steady state measurements made prior to three of the tests.

3.1 EQUIPMENT UNDER TEST

The Kerr Addison Mines hoist equipment consists of a three-phase synchronous motor driving a pair of identical dc generators. These dc generators supply power to the armatures of a matched pair of dc motors which perform the hoisting. Appendix A includes a simplified drawing of the synchronous motor connections and instrument transformer locations along with a listing of the nameplate ratings for the synchronous generator, dc motors and starting autotransformer.

The motor's red and blue phase currents and phase-to-phase terminal voltage were directly monitored on a high speed oscillograph during each of the motor starting tests.

3.2 MOTOR STARTING TEST RESULTS

During the starting procedure the unloaded synchronous motor is supplied through a step down autotransformer with selectable taps of 30%, 35% and 40%. The Kerr Addison Mines staff could not provide any information on the currently selected tap setting. The initial magnitude of the starting currents for each of the tests was measured to be 700 A rms on the supply side of the autotransformer, or approximately 2000 A rms at the motor terminals. This value is quite reasonable given the machine's nameplate rating of 1255 A rms.

After 35 to 40 seconds the motor reaches synchronous speed and the connections to the motor terminals are automatically switched from the autotransformer secondary to the incoming 2300 V supply by first opening breaker 6N and then closing breaker 42 (refer to Figure A-1). During the switching process, current to the motor is interrupted for approximately seven cycles (0.28 seconds). Figure 14 is an oscillograph record of the supplied voltage and currents during the current interruption and subsequent breaker closure. The motor current following the closure of breaker 42 was measured to be approximately 1130 A rms. The switchover operation results in a short duration voltage decrease which is larger in magnitude than the voltage drop encountered during the initial reduced voltage starting.

The voltage declines measured at Wawaitin GS, Abitibi Canyon GS and Martindale TS/FC were below 1% for each of the four tests. The voltage decline measurements at Kerr Addison TS are listed below.

- Test M1 (K1Z in service) -5.6% start, -12.0% switching
- Test M2 (K1Z out of service) -6.8% start, -12.6% switching
- Test M3 (K1Z out of service and Copper Cliff 10S1R open) -8.0% start, -13.0% switching
- Test M4 (K1Z out of service and Canyon G1 out of service) -7.6% start, -13.6% switching

Clearly, removal of the interconnection to Hydro Quebec has only a small effect on the voltage decline at Kerr Addison TS during the motor starting operation. These results are in reasonable agreement with the preliminary simulation results which predicted voltage declines of between 8% and 9% at Kerr Addison TS for the various tests.

Figure 15 is a record of motor starting test M3 in which the 25 Hz system was operated as an island with both the interconnection to the Hydro Quebec system disconnected and the Martindale frequency changers separated from the system via opening of breaker 10S1R at Copper Cliff TS. The appearance of the 0.08 Hz mode of oscillation is clearly evident throughout this record. Figure 16 illustrates the performance of the system during test M4 in which the motor was started with Abitibi Canyon G1 off line. From both of these records it can be seen that as the motor approaches synchronous speed, and the slip frequency decreases towards zero, the system modes of oscillation are excited resulting in swings measurable throughout the system. This phenomenon is due to the motor saliency, which results in a variation of the motor's impedance at twice the slip frequency, resulting in modulation of the current and power supply to the motor. Although not critical in any of the staged tests performed, the potential side effects of the motor starting operation should be considered when operating in configurations associated with poor damping of the system modes of oscillation.

4.0 EXCITATION AND GOVERNING SYSTEMS

A number of measurements and additional tests were performed to assess the effect of the excitation and governing systems at Abitibi Canyon GS and Martindale TS/FC.

4.1 ABITIBI CANYON G1

4.1.1 Excitation System

The Abitibi Canyon G1 unit is outfitted with a General Electric GFA-4 voltage regulator and rotating DC pilot and main exciters mounted on the generator shaft. The pilot exciter is a self-excited compound-wound DC machine. A variable resistive bridge arrangement between the pilot exciter output and the main exciter field winding is used to control the applied excitation.

The GFA-4 is an indirect-acting rheostatic voltage regulator which operates in one of two modes, depending on the magnitude of the voltage error (i.e. difference between measured generator terminal voltage and reference setting) [3,4].

For small errors (e.g. 1% to 10%), a motor-operated rheostat in the main exciter field provides slow-adjustment capability. There is a voltage error deadband of approximately $\pm 1\%$ which must be overcome before the regulator will act. Once the deadband is overcome the rate at which the field voltage is adjusted increases with increasing voltage error. These two features combine to limit hunting of the regulator. Due to the age of the voltage regulator its response is somewhat unpredictable. Tests performed with the Canyon unit on open circuit revealed that on occasion, the regulator does not respond to errors as large as 2 or 3%.

For larger voltage errors rapid correction is obtained by the operation of fast raise/lower relays which short or insert resistors in the main exciter field. According to the manufacturer's settings, this field forcing is usually set to operate for voltage errors exceeding 5%. Tests revealed that the field forcing action was not initiated for errors below 10%. Again this appears to be due to the age and condition of the voltage regulator mechanical contact arrangement.

Given the deadband and slow operating speed of this regulator for small terminal voltage deviations, it is clear that it does not participate at all in the system mode of oscillation at 0.4 Hz. It also seems unlikely that it is the primary cause of the slower 0.08 Hz mode, since during these oscillations the peak-to-peak voltage deviations measured at Abitibi Canyon GS were at or below 2% (refer to Figures 10 and 15a).

Figure 17 [4] is a block diagram representing the operation of the regulator/exciter. Parameters obtained from test data for the Canyon unit are attached as Table 4. These parameters may be used in either the "IEEEX4" model of the PTI Power System Simulator package or in the "IEX Type 9" model of the TSSIMU program to simulate voltage regulation on the unit. Unfortunately, neither of these models includes a voltage error deadband in the input. Without this deadband the system (both modelled and actual) will have an inherent tendency to hunt, especially on open circuit. To compensate for shortcomings in the model and to provide a better representation of the actual overall response to small terminal voltage changes, the motor-operated rheostat travel time (T_{RH}) was set to an artificially high value.

4.1.2 Governing System

The governor on Abitibi Canyon G1 is a Woodward Cabinet Actuator mechanical-hydraulic governor. The unit's compensating crank and pilot valve restoring lever settings were noted and used to produce an estimate of the turbine gain and temporary droop settings. These settings along with a number of typical parameter values are listed in Table 5 in a format suitable for use in either the PTI or TSSIMU simulation programs. It should be noted that two of the most critical parameters, the dashpot reset time, Tr, and the water starting time, Tw, are typical estimates rather than measured or calculated values for this unit. Nevertheless, the model data,

provided in Table 5, should be sufficient to simulate the limited participation of the governor under most conditions. Monitoring of the gate position during the staged tests revealed that, except for islanded conditions, the governor at Abitibi Canyon was not involved in the system mode of oscillations.

4.2 MARTINDALE FC1

The 25 Hz and 60 Hz sides of Martindale FC1 are equipped with Westinghouse Type WMA magnetic amplifier voltage regulators. Initial results provided by the System Planning Division indicated that the low frequency system mode of oscillation is not sensitive to the response characteristics of these regulators. To qualitatively assess the effect of the 25 Hz regulator on these modes of oscillation, the unit was placed on manual (i.e. constant excitation) for a short period. Figure 18 is a record of the transfer between manual and voltage regulator control. Analysis of the records obtained during the period that the unit was on manual indicated that the FC1 terminal voltage swings were slightly reduced whereas the real power and frequency swings were virtually unaffected. This tends to support the initial study results and confirms that modification of the regulator dynamics will not improve the overall system response to the low frequency mode of oscillation.

4.3 WAWAITIN GS

At the present time the units at Wawaitin GS are not equipped with governors or voltage regulators. Work is currently underway to install small static excitation systems on each of the units and trial tests have already been conducted to assess their performance.

Given the limited damping which exists on the NE 25 Hz system, the addition of fast-responding high gain voltage regulators on these units is clearly out of the question. The addition of power system stabilizers, which would be required if a high transient regulator gain were desired, is uneconomical for units of this size. Instead, a low regulator gain setting coupled with a transient gain reduction network will be used. The System Planning Division is in the process of establishing settings for these regulators which will ensure that their addition to the system will not significantly reduce damping of the prevailing modes of oscillation.

5.0 CONCLUSIONS AND RECOMMENDATIONS

Removal of the K1Z interconnection to Hydro Quebec had little impact on the results of the staged dynamic stability and motor starting tests. Although the system exhibited positive damping for each of the tested system configurations, customer load and generation behaviour appears to have a significant impact on the appearance and damping of the 0.4 Hz mode of oscillation. Voltage decline measured during starting of the Kerr Addison Mines motor was acceptable and relatively insensitive to the system's operating configuration.

Digital simulations of the staged tests were reasonably accurate given the approximate representation of the NE 25 Hz system. The information contained within this report should allow for validation of the system representation and improve accuracy of simulations performed for planning and operating strategy development.

The test results support the Regional Operating practice of splitting the system at Timmins TS as a control action to eliminate persistent or growing oscillations. With a validated system representation, the Power System Operations Division may be able to provide additional operating strategies.

Areas which may require further study include the following:

- One measure which could be considered for improvement of the system's dynamic stability characteristics is the addition of a static excitation system and power system stabilizer to the Abitibi Canyon G1 unit. Although this option is relatively costly, replacement of the existing exciter and voltage regulator would have the additional benefits of improving voltage regulation and unit reliability.

- Once the interconnection to Hydro Quebec is removed, extended outages to Abitibi Canyon G1 and Martindale FC1 would necessitate meeting load requirements on the 25 Hz system via the two small frequency changers. Should digital studies of this configuration prove inconclusive, further field tests could be conducted to ascertain the feasibility of this mode of operation.

- Given the increased possibility of islanded operation of the system, there may be some benefit in establishing settings for the Abitibi Canyon G1 governor based on providing optimal performance under these conditions.

- System Planning Division and Research Division, in conjunction with the NE Region, will establish, implement and test appropriate settings on the new Wawaitin GS exciters to avoid any degradation of damping on the system.

5.1 ACKNOWLEDGEMENTS

I wish to thank the Northeastern Region P&C and Operating Staff for their work in instrumenting and coordinating these tests. In particular, the work of Milan Jacklic and Paul Lynch is gratefully acknowledged. Regional staff are requested to pass on our thanks to the staff of Kerr Addison Mines for their cooperation and patience during the motor starting tests. Special thanks to Bruno Pietrantonio of the System Studies Section for his expert assistance throughout this test.

Approved:

A. F. Baljet

A.F. Baljet
Manager
Electrical Research Department

Submitted:

G. Roger Bérubé

G.R. Bérubé
Engineer
System Studies Section

GRB:td

REFERENCES

[1] "Minutes of Northeastern Region 25 Hz System Test Meeting", Mr. D.W. McCarrel, March 22, 1988.

[2] "Northeastern Region 25 Hz System Test", Memorandum from P.C. Maenhaut to Mr. B.R. Rodie and Mr. H.W. Parish, May 10, 1988.

[3] "General Electric Voltage Regulator Type GFA-4 Instruction Manual", Number GEH-847A.

[4] "Excitation System Models for Power System Stability Studies", IEEE Committee Report, IEEE Transactions, Vol. PAS-100, No 2, February 1981.

TABLE 1
DYNAMIC STABILITY TESTS, MAY 26, 1988

TEST NUMBER	CIRCUIT K1Z	CANYON GS G1	MARTINDALE FCs	WAWAITIN GS	DISTURBANCE	FIGURE #
D-1	I/S (see note 1)	I/S loaded as required	FC1, FC7 I/S FC6 O/S	all units I/S	trip Wawaitin G2	2
D-2a	O/S	I/S loaded as required	FC1, FC7 I/S FC6 O/S	all units I/S	trip Wawaitin G2	3
D-2b	O/S	I/S condensing	FC1, FC7 I/S FC6 O/S	all units I/S	trip Wawaitin G1	4,5
D-2c	O/S	O/S	FC1, FC7 I/S FC6 O/S	G2 O/S	trip Wawaitin G1	6
D-3	O/S	I/S	FC1, FC7 I/S FC6 O/S	all units I/S	trip Wawaitin G1 & G2	7
D-4	O/S	I/S	FC1 I/S FC6,FC7 O/S	all units I/S	trip Wawaitin G1 & G2	8
D-5	O/S	I/S	FC1, FC7 I/S FC6 O/S	all units I/S	open breaker 19M1T at Timmins TS trip Wawaitin G1	9

1. I/S = in service, O/S = out of service (separated from system)
2. All Northeastern 25 Hz system elements in-service unless otherwise indicated
3. Lower Sturgeon GS and Sandy Falls GS units loaded as required.

TABLE 2
MOTOR STARTING TESTS, MAY 27, 1988

TEST NUMBER	CIRCUIT K1Z	CANYON GS G1	MARTINDALE FCs	WAWAITIN GS	DISTURBANCE
M-1	I/S (see Note 1)	I/S	FC1, FC7 I/S FC6 O/S	G4 I/S G1, G2, G3 O/S	start Kerr Addison hoist motor
M-2	O/S	I/S	FC1, FC7 I/S FC6 O/S	all units O/S	start Kerr Addison hoist motor
M-3	O/S	I/S	breaker 10S1R opened at Copper Cliff TS separating Martindale FCs from system	all units O/S	start Kerr Addison hoist motor
M-4	O/S	O/S	FC1, FC7 I/S FC6 O/S	G3, G4 I/S G1, G2 O/S	start Kerr Addison hoist motor

1. I/S = in service, O/S = out of service (separated from system)
2. All Northeastern 25 Hz system elements in-service unless otherwise indicated
3. Lower Sturgeon GS and Sandy Falls GS units loaded as required

TABLE 3
STEADY STATE READINGS FOR
DYNAMIC STABILITY AND MOTOR STARTING TESTS

TEST NUMBER	INCO TRANSFER	SANDY FALLS GS	LOWER STURGEON GS	HUNTA TRANSFER
D-1	5 MW OUT 2 MVAR OUT 130 kV	2.6 MW OUT 1.1 MVAR OUT 12.5 kV	5.2 MW OUT 0 MVAR 2.3 kV	0 MW 3 MVAR IN 130 kV
D-2a	AS ABOVE	AS ABOVE	AS ABOVE	AS ABOVE
D-2b	AS ABOVE	AS ABOVE	AS ABOVE	AS ABOVE
D-2c	AS ABOVE	AS ABOVE	AS ABOVE	AS ABOVE
D-3	5 MW OUT 3 MVAR OUT 125 kV	2.6 MW OUT 0 MVAR 12.5 kV	1 MW OUT 0.4 MVAR IN 2.5 kV	0 MW 2 MVAR IN 128 kV
D-4	AS ABOVE	AS ABOVE	AS ABOVE	AS ABOVE
D-5	3 MW OUT O MVAR 128 kV	2.6 MW OUT 0.4 MVAR OUT 12.5 kV	5.2 MW OUT 0.7 MVAR OUT 2.3 kV	2 MW IN - MVAR 126 kV
M-1	NO READING	NO READING	NO READING	NO READING
M-2	5 MW OUT 3 MVAR OUT 121 kV	2.6 MW OUT 0.4 MVAR OUT 12.5 kV	5.2 MW OUT 0.7 MVAR OUT 2.3 kV	2 MW OUT - MVAR 126 kV
M-3	AS ABOVE	AS ABOVE	1 MW OUT 0 MVAR OUT 2.3 kV	0 MW OUT - MVAR - kV
M-4	6 MW OUT 0 MVAR 129 kV	2.6 MW OUT 1 MVAR OUT 12.5 kV	5.2 MW OUT 0 MVAR 2.3 kV	1 MW OUT - MVAR 127 kV

1. "OUT" MEANS FROM THE GENERATOR OR CUSTOMER TO THE SYSTEM
2. "IN" MEANS FROM THE SYSTEM TO THE CUSTOMER OR GENERATOR
3. BLANK FIELDS INDICATE NO READING

TABLE 4
ABITIBI CANYON G1 VOLTAGE REGULATOR/EXCITER PARAMETERS

PTI Model IEEEX4
TSSIMU Model IEX Type 9

T_R =	0	Terminal Voltage Transducer Time Constant
T_{RH} =	80	Motor Operated Rheostat Travel Time
K_V =	0.1	Field Forcing Voltage Error
V_{RMAX} =	4	Maximum Field Forcing
V_{RMIN} =	0	Minimum Field Forcing
T_E =	1.25	Main Exciter Time Constant
K_E =	1.2	Main Exciter Gain
S_E (3.375) =	0.1	Exciter Saturation Characteristics
S_E (4.5) =	0.35	

TABLE 5
ABITIBI CANYON G1 GOVERNOR MODEL PARAMETERS

Description	TYPE 10[1]	HYGOV[1]
Servo System Gain	Q = 6	-
Servo System Time Constant	-	T_g = 0.8
Turbine Gain	-	A_t = 1.11
Permanent Droop	R_p = 0.04	R = 0.04
Temporary Droop	R_t = 0.2	r = 0.2
Water Starting Time	T_w = 1.0	T_w = 1.0
Dashpot Reset Time	T_r = 5.0	-
Full Load Gate	G_{FL} = 1	-
No Load Gate (No Load Flow)	G_{NL} = 0.1	q_{NL} = 0.1
Maximum Gate Limit	-	G_{MAX} = 1
Minimum Gate Limit	-	G_{MIN} = 0
Maximum Gate Opening Velocity	$R_{MAX\ (open)}$ = 0.10	R_{LIM} = ± 0.15
Maximum Gate Closing Velocity	$R_{MAX(close)}$ = 0.20	
Gate Buffer Region	G_{BF} = 0.10	-
Maximum Gate Closing Velocity in Buffer Region	$R_{BF(close)}$ = 0.025	-
Power at Full Load Gate (pu on Gen. MVA Base)	P_{MAX} = 1	-

Notes: 1) Blank fields indicate parameters not included in model.

APPENDIX A

KERR ADDISON MINES HOIST EQUIPMENT NAMEPLATE RATINGS

GE Synchronous Motor:

Type TS	Class 6-5000-5000		Form AC
KVA 5000	HP 5000	Volts 2300	Amp 1255
RPM 500	25 Hz	3-Phase	0.8 P.F.
Excitation 125 V	Amps Max = 330		
Temp Rise 50°C stator	60°C rotor		

Twin GE DC Generators (and Matching Motors):

Type MCF-12	1750 kW	Speed 500 RPM

Volts Full Load = 600

Amps Full Load = 2920

Shunt Wound, Separately Excited 250 V

GE Autotransformer:

Type HT Volts 2300

Starting Taps - 30%, 35%, 40%

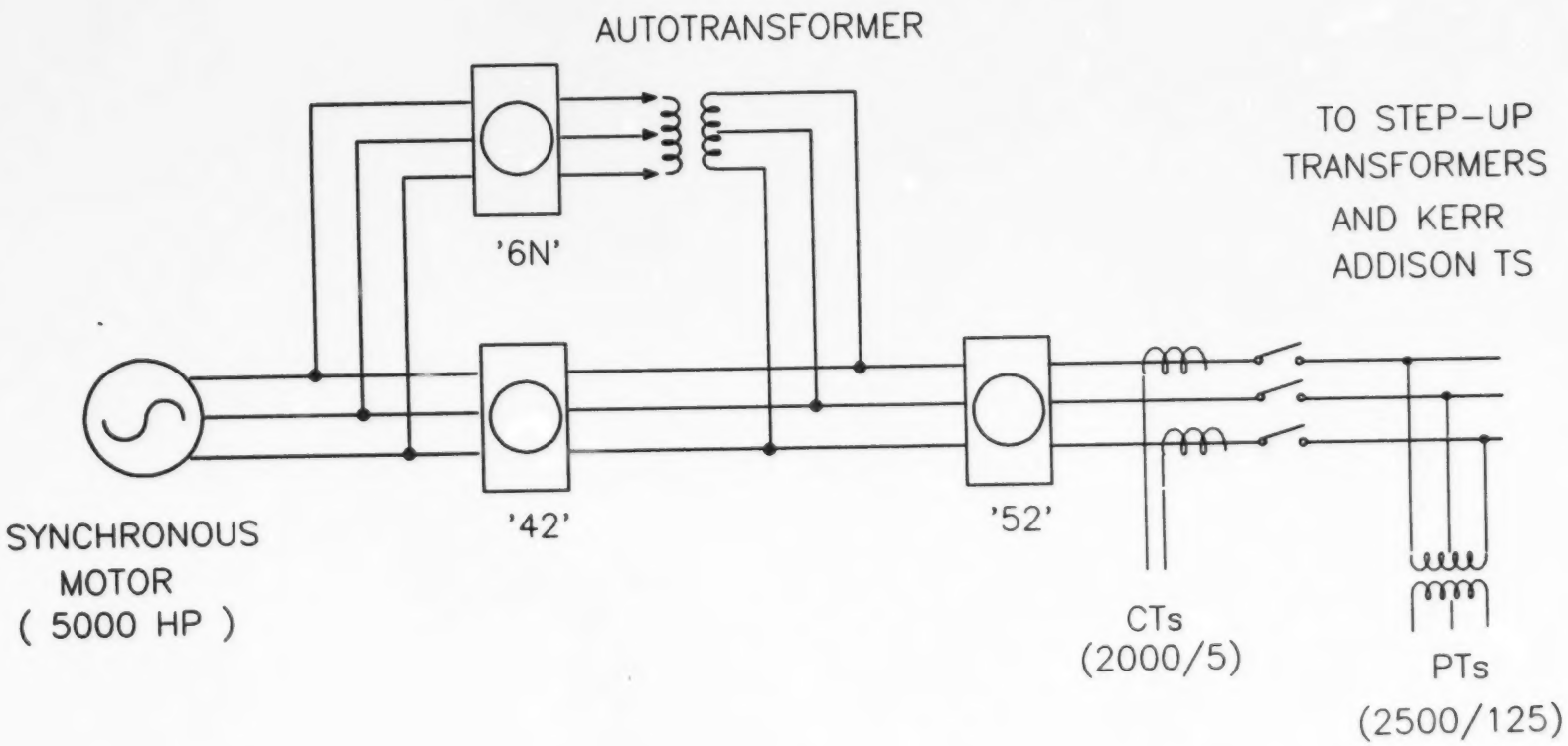


FIGURE A-1 : KERR ADDISON MINE HOIST MOTOR
ELECTRICAL ARRANGEMENT

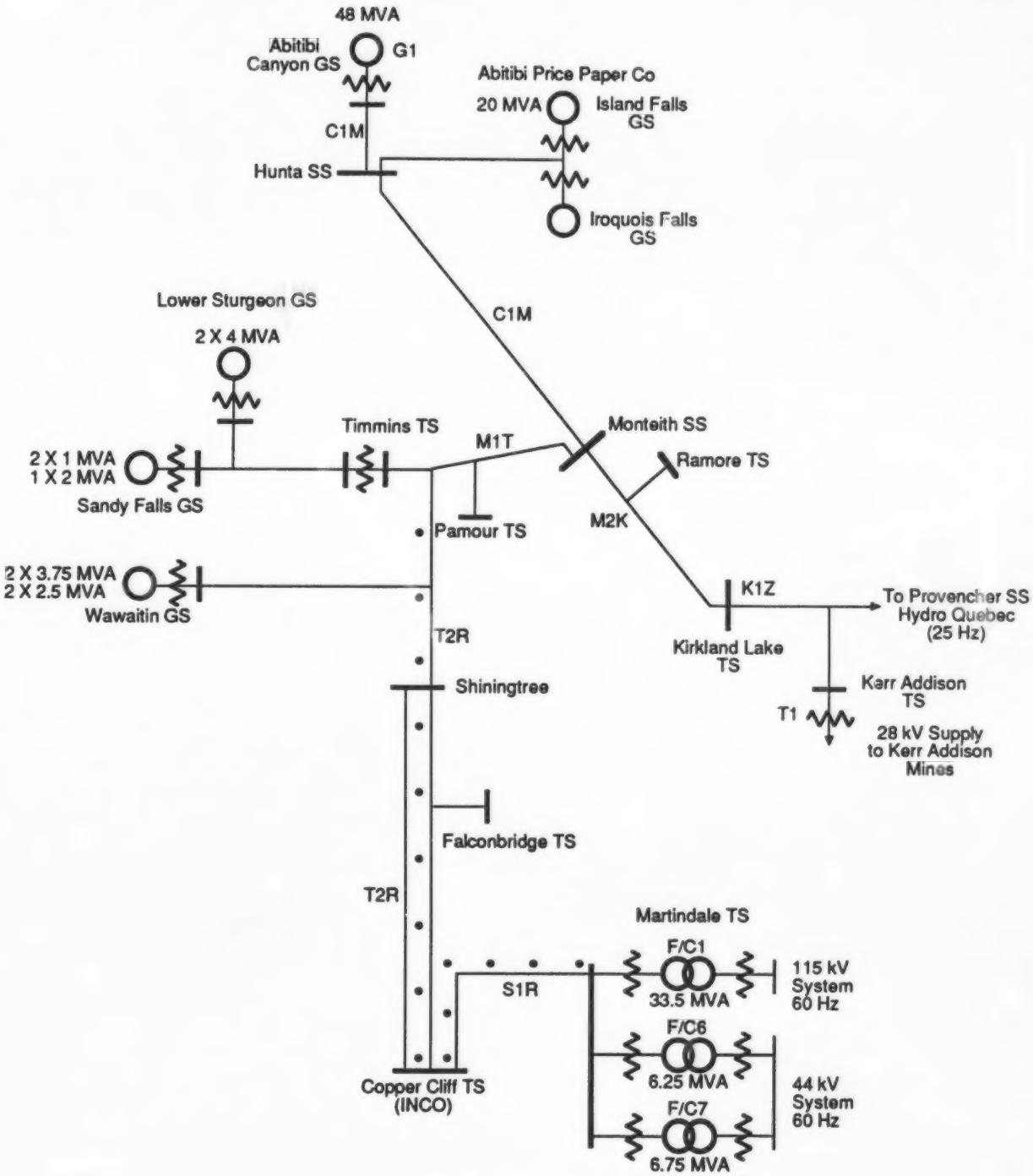


FIGURE 1

NORTHEASTERN REGION 25 Hz SYSTEM

177296-RD
JA 6 DEK

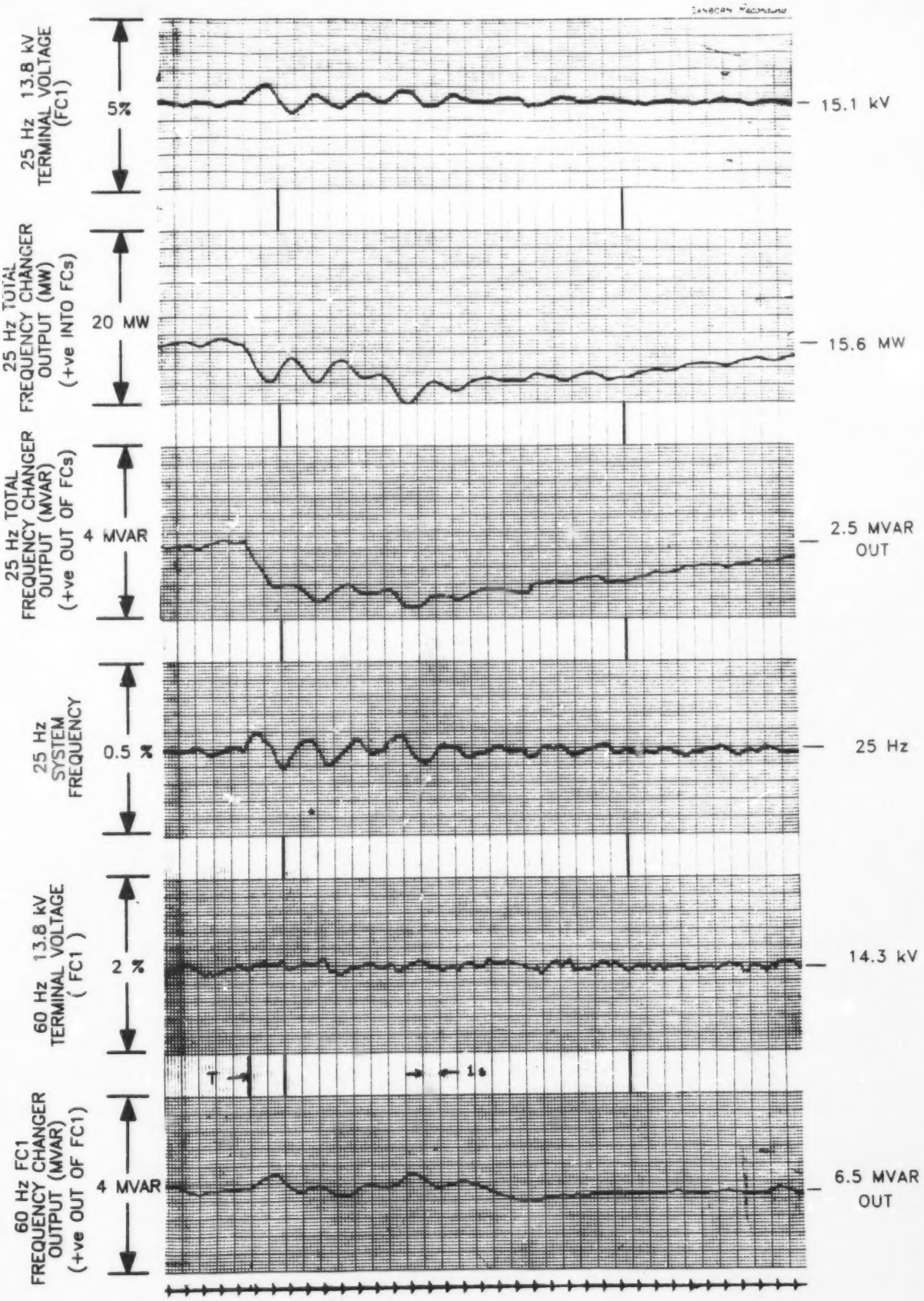

25 Hz 13.8 kV TERMINAL VOLTAGE (FC1)
5%
15.1 kV
25 Hz TOTAL FREQUENCY CHANGER OUTPUT (MW) (+ve INTO FCs)
20 MW
15.6 MW
25 Hz TOTAL FREQUENCY CHANGER OUTPUT (MVAR) (+ve OUT OF FCs)
4 MVAR
2.5 MVAR OUT
25 Hz SYSTEM FREQUENCY
0.5 %
25 Hz
60 Hz 13.8 kV TERMINAL VOLTAGE (FC1)
2 %
14.3 kV
T
1s
60 Hz FC1 FREQUENCY CHANGER OUTPUT (MVAR) (+ve OUT OF FC1)
4 MVAR
6.5 MVAR OUT

FIGURE 2a : MARTINDALE TS/FC
TEST 01 – CIRCUIT K1Z I/S, MARTINDALE FC1,FC7 I/S, ALL WAWAITIN UNITS I/S, TRIP WAWAITIN G2

88-231

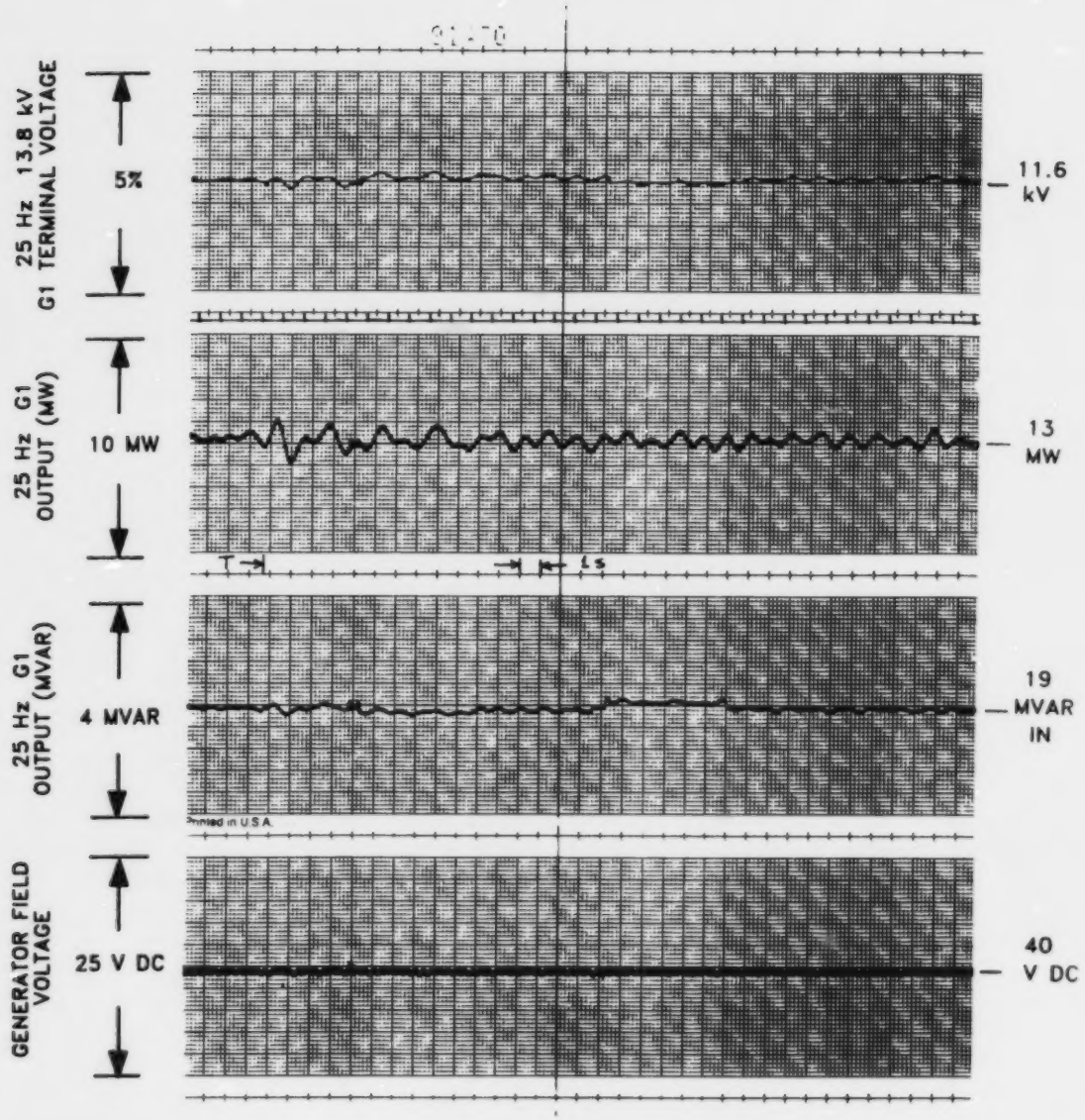


FIGURE 2b : ABITIBI CANYON GS

TEST D1 – CIRCUIT K1Z I/S, MARTINDALE FC1, FC7 I/S
ALL WAWAITIN UNITS I/S, TRIP WAWAITIN G2

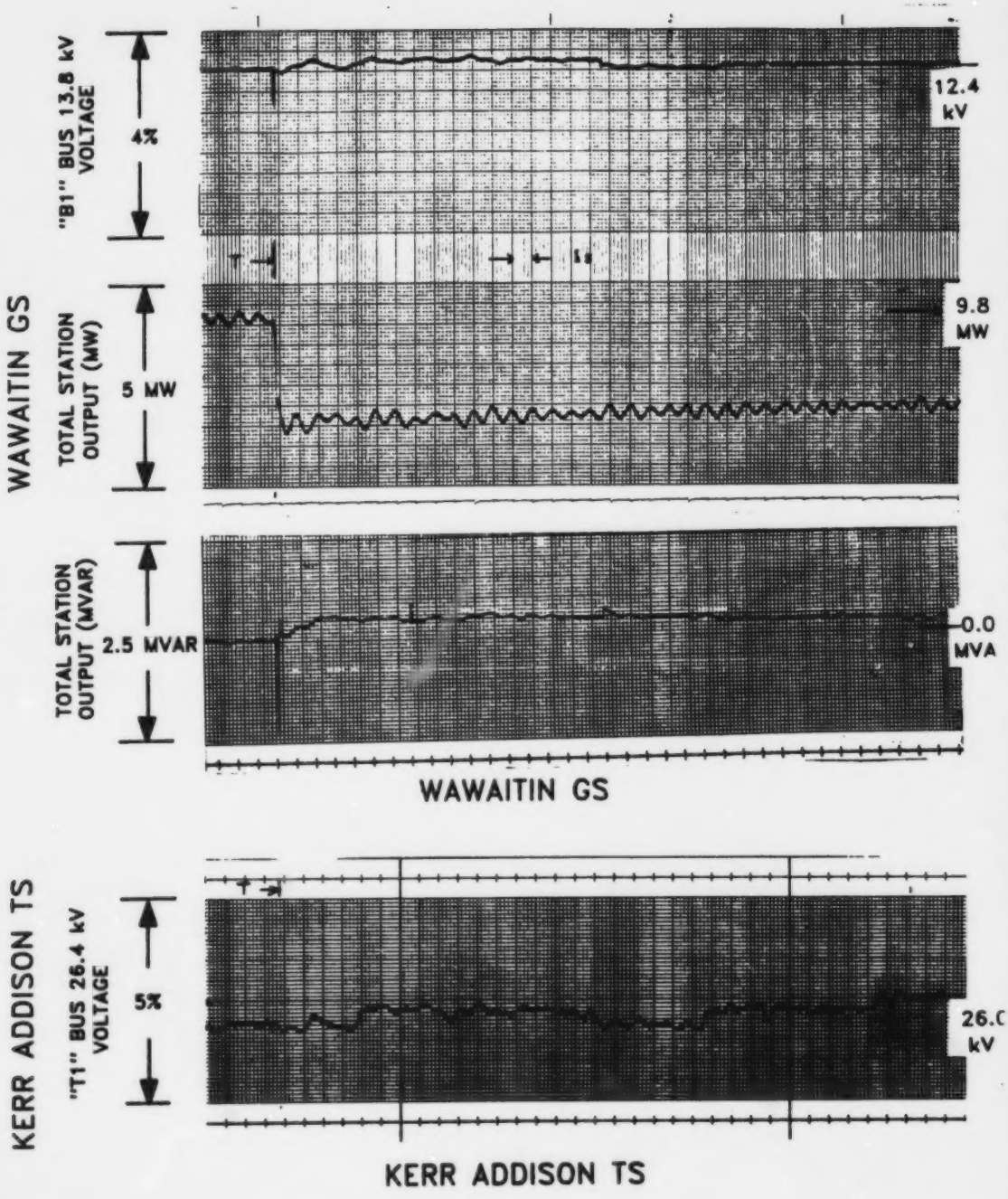


FIGURE 2c : WAWAITIN GS, KERR ADDISON TS

TEST D1 – CIRCUIT K1Z I/S, MARTINDALE FC1, FC7 I/S
ALL WAWAITIN UNITS I/S, TRIP WAWAITIN G2

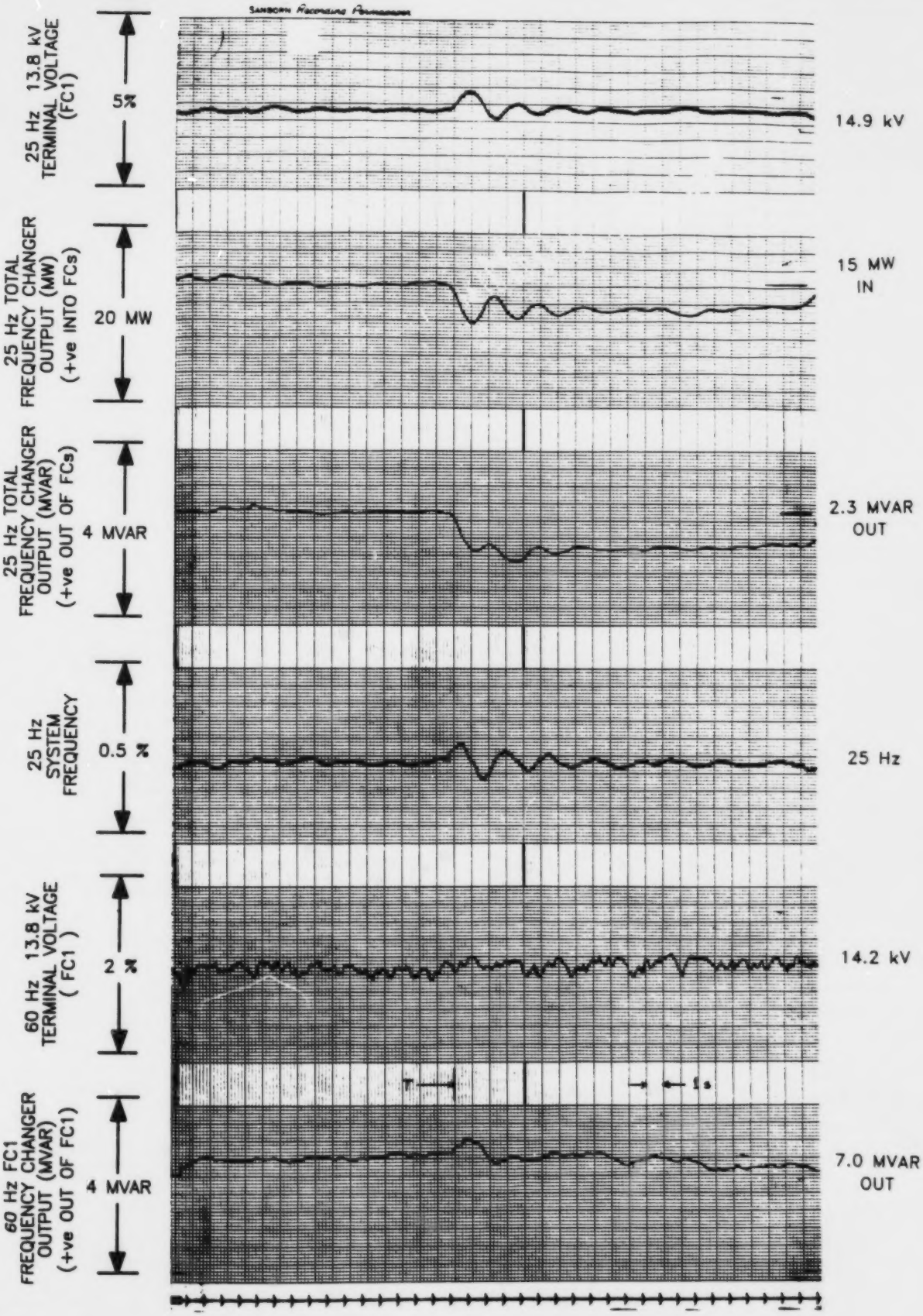

25 Hz 13.8 kV TERMINAL VOLTAGE (FC1)
5%
14.9 kV
25 Hz TOTAL FREQUENCY CHANGER OUTPUT (MW) (+ve INTO FCs)
20 MW
15 MW IN
25 Hz TOTAL FREQUENCY CHANGER OUTPUT (MVAR) (+ve OUT OF FCs)
4 MVAR
2.3 MVAR OUT
25 Hz SYSTEM FREQUENCY
0.5 %
25 Hz
60 Hz 13.8 kV TERMINAL VOLTAGE (FC1)
2 %
14.2 kV
T
1s
60 Hz FC1 FREQUENCY CHANGER OUTPUT (MVAR) (+ve OUT OF FC1)
4 MVAR
7.0 MVAR OUT

FIGURE 3a : MARTINDALE TS/FC

TEST D2a – CIRCUIT K1Z O/S, MARTINDALE FC1,FC7 I/S
ALL WAWAITIN UNITS I/S, TRIP WAWAITIN G2

88-231

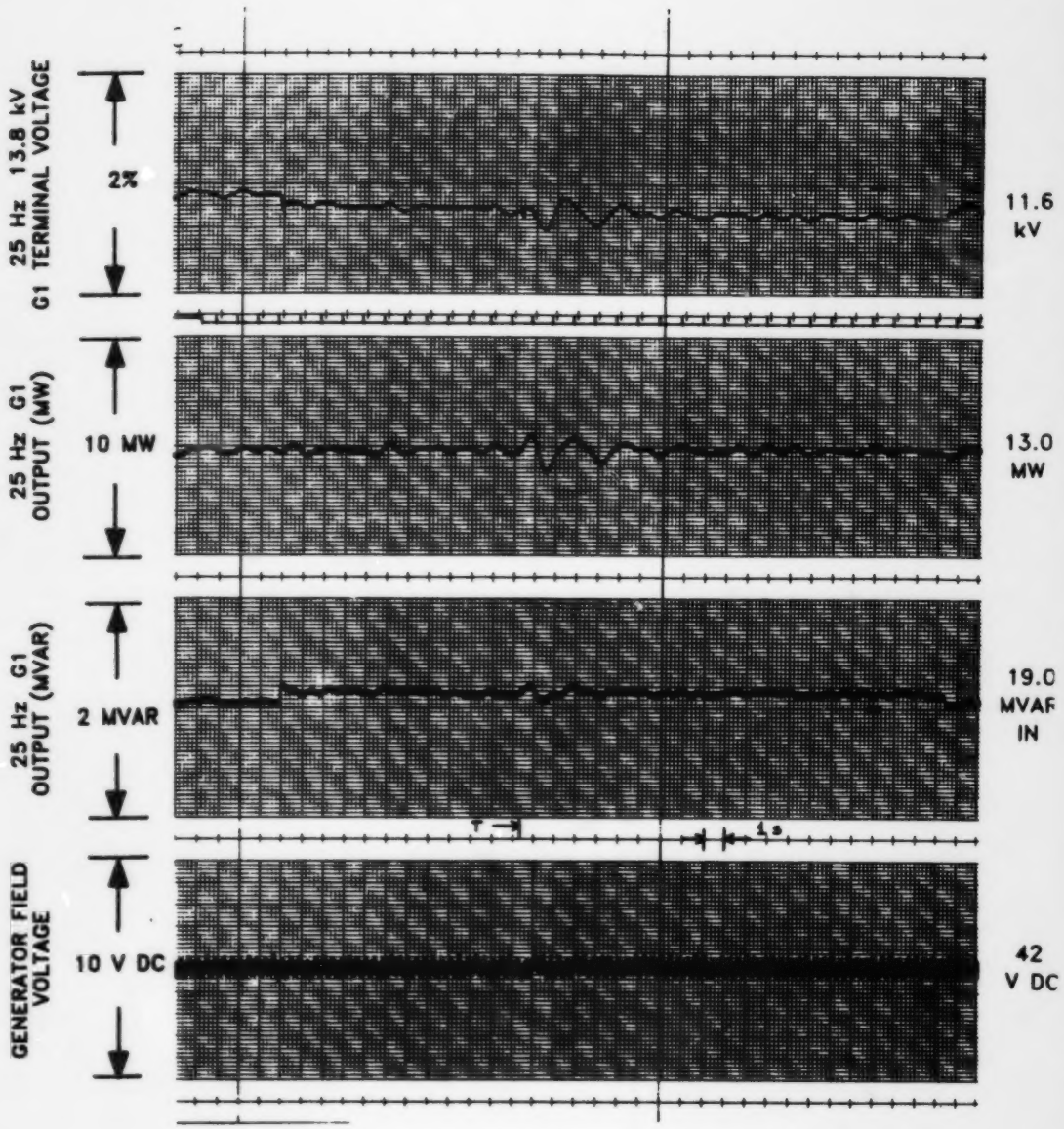


FIGURE 3b : ABITIBI CANYON GS

TEST D2A – CIRCUIT K1Z O/S, MARTINDALE FC1, FC7 I/S
ALL WAWAITIN UNITS I/S, TRIP WAWAITIN G2

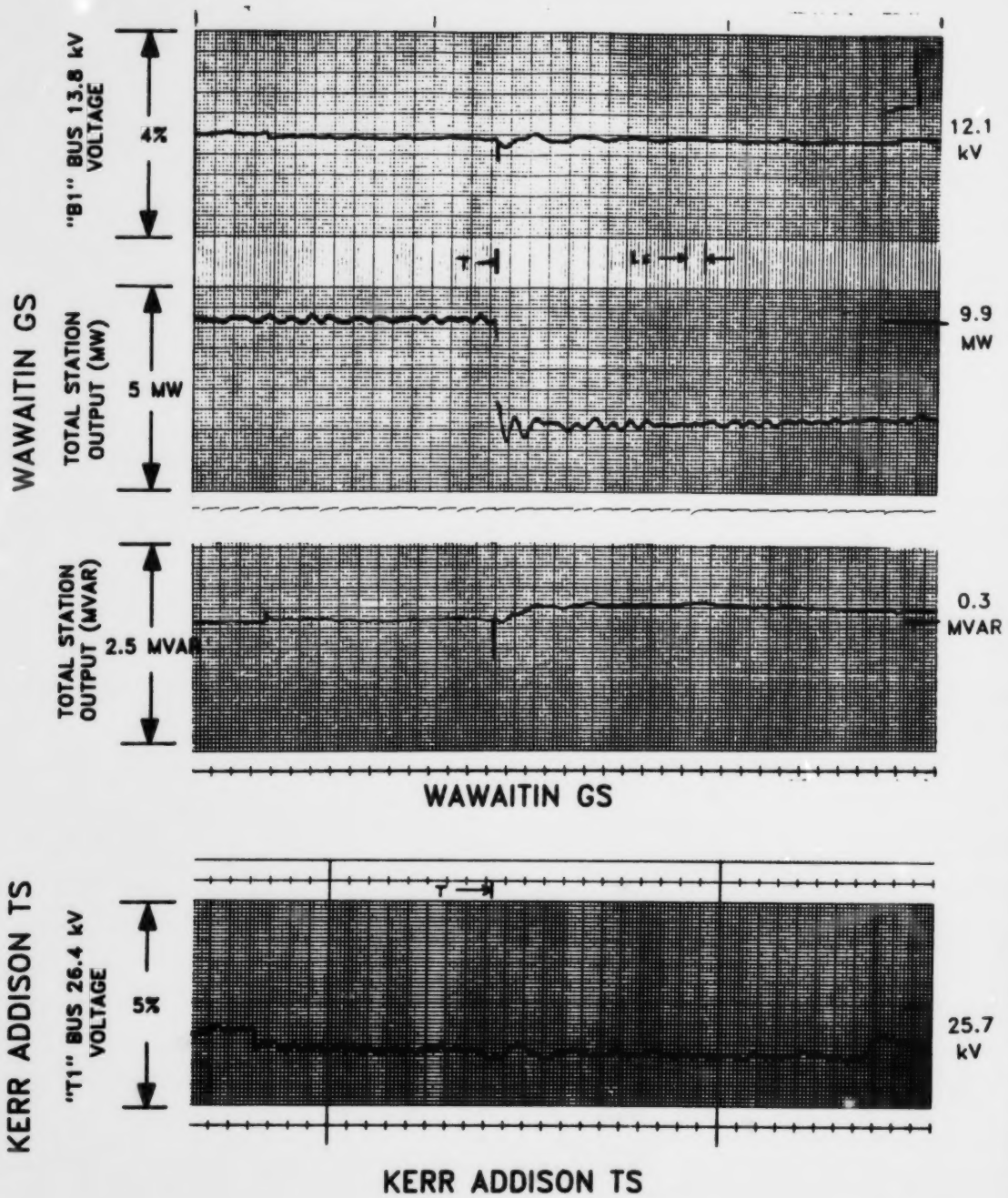


FIGURE 3c : WAWAITIN GS, KERR ADDISON TS

TEST D2A – CIRCUIT K1Z O/S, MARTINDALE FC1, FC7 I/S
ALL WAWAITIN UNITS I/S, TRIP WAWAITIN G2

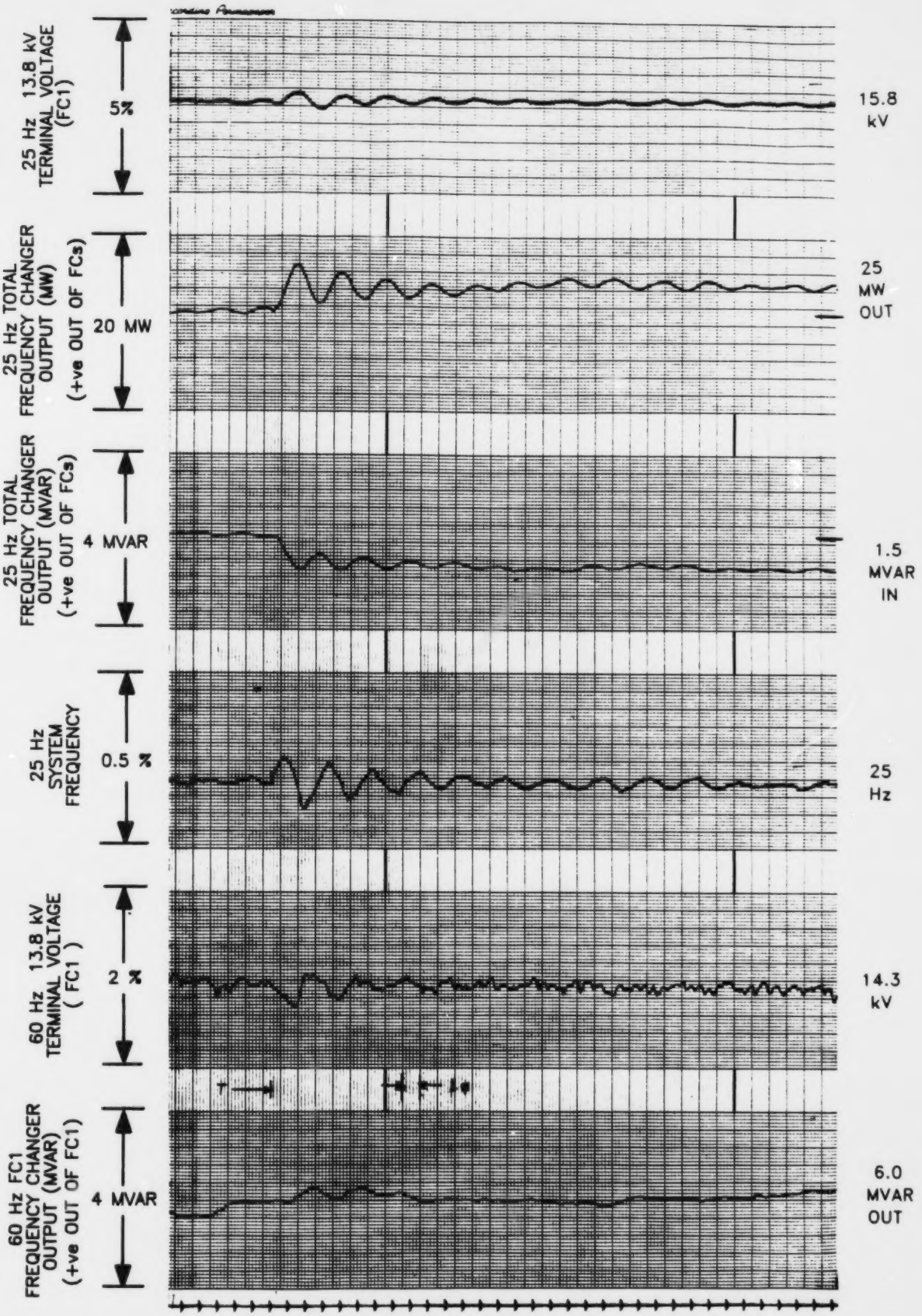

25 Hz 13.8 kV TERMINAL VOLTAGE (FC1)
5%
15.8 kV
25 Hz TOTAL FREQUENCY CHANGER OUTPUT (MW) (+ve OUT OF FCs)
20 MW
25 MW OUT
25 Hz TOTAL FREQUENCY CHANGER OUTPUT (MVAR) (+ve OUT OF FCs)
4 MVAR
1.5 MVAR IN
25 Hz SYSTEM FREQUENCY
0.5 %
25 Hz
60 Hz 13.8 kV TERMINAL VOLTAGE (FC1)
2 %
14.3 kV
60 Hz FC1 FREQUENCY CHANGER OUTPUT (MVAR) (+ve OUT OF FC1)
4 MVAR
6.0 MVAR OUT

FIGURE 4a : MARTINDALE TS/FC
TEST D2b – CIRCUIT K1Z O/S, MARTINDALE FC1,FC7 I/S, ALL WAWAITIN UNITS I/S, CANYON G1 CONDENSING, TRIP WAWAITIN G1

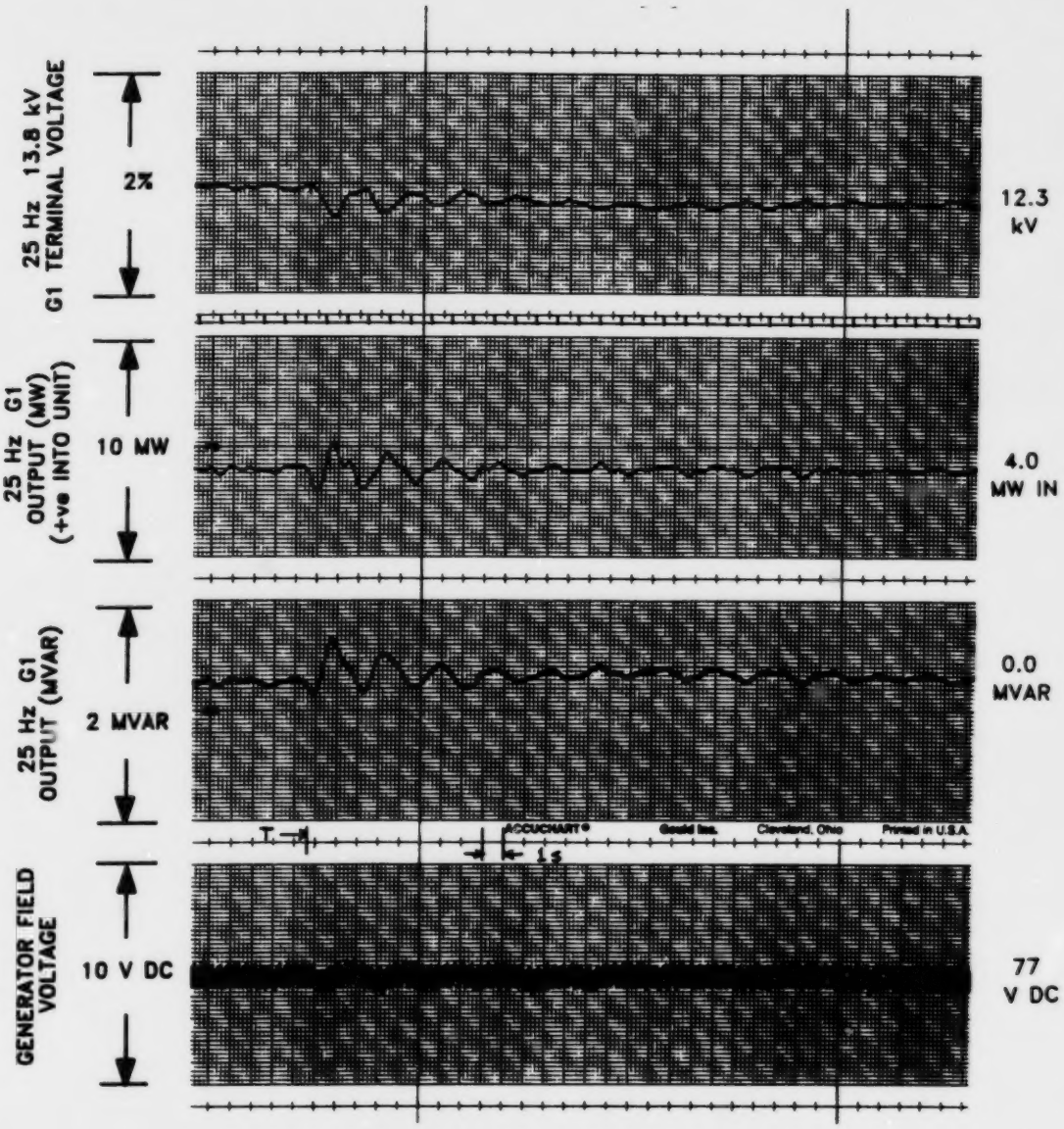


FIGURE 4b : ABITIBI CANYON GS

TEST D2B – CIRCUIT K1Z O/S, MARTINDALE FC1, FC7 I/S, ALL WAWAITIN UNITS I/S, CANYON G1 CONDENSING, TRIP WAWAITIN G1

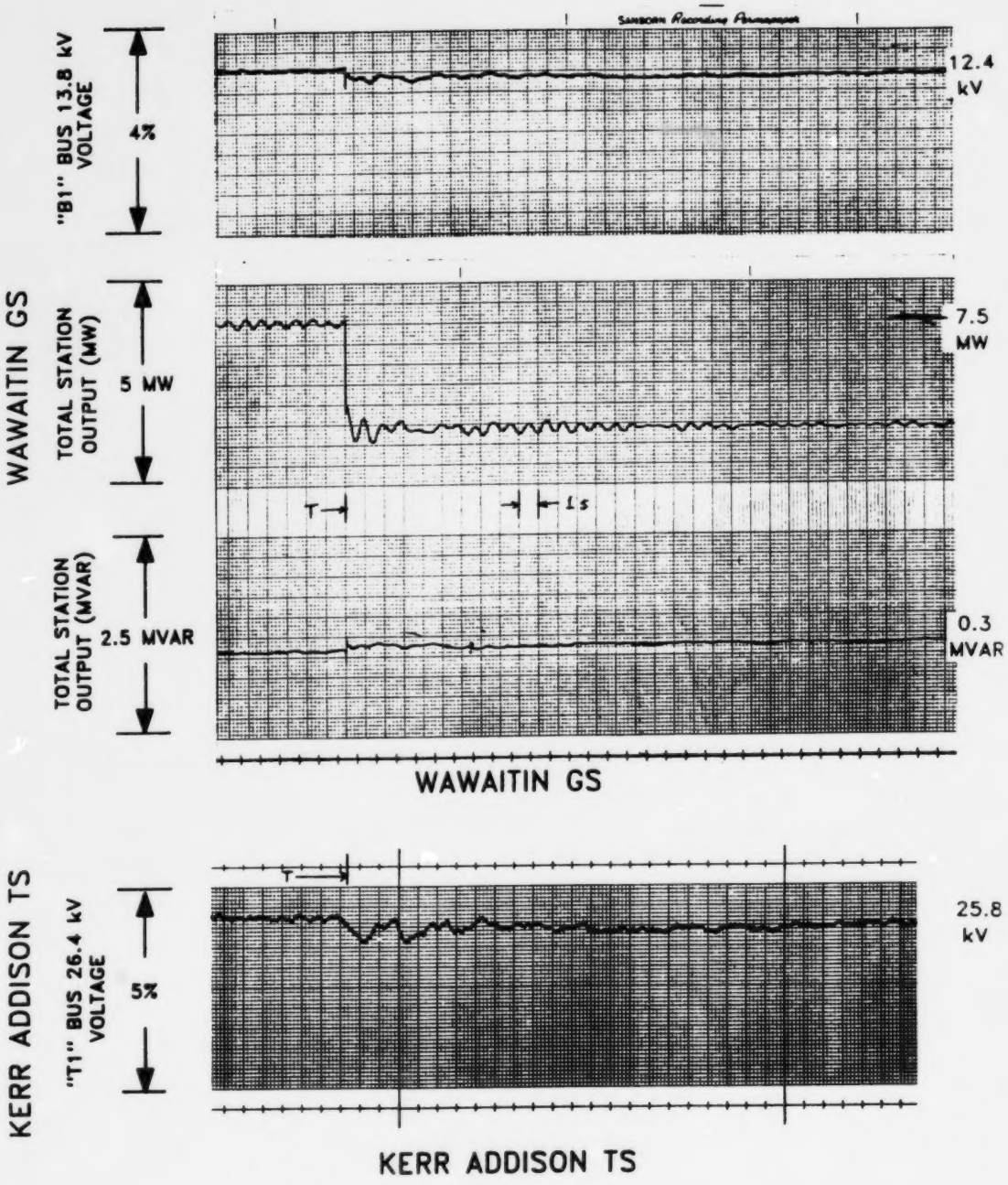


FIGURE 4c : WAWAITIN GS, KERR ADDISON TS

TEST D2B – CIRCUIT K1Z O/S, MARTINDALE FC1, FC7 I/S, ALL WAWAITIN UNITS I/S, CANYON G1 CONDENSING, TRIP WAWAITIN G1

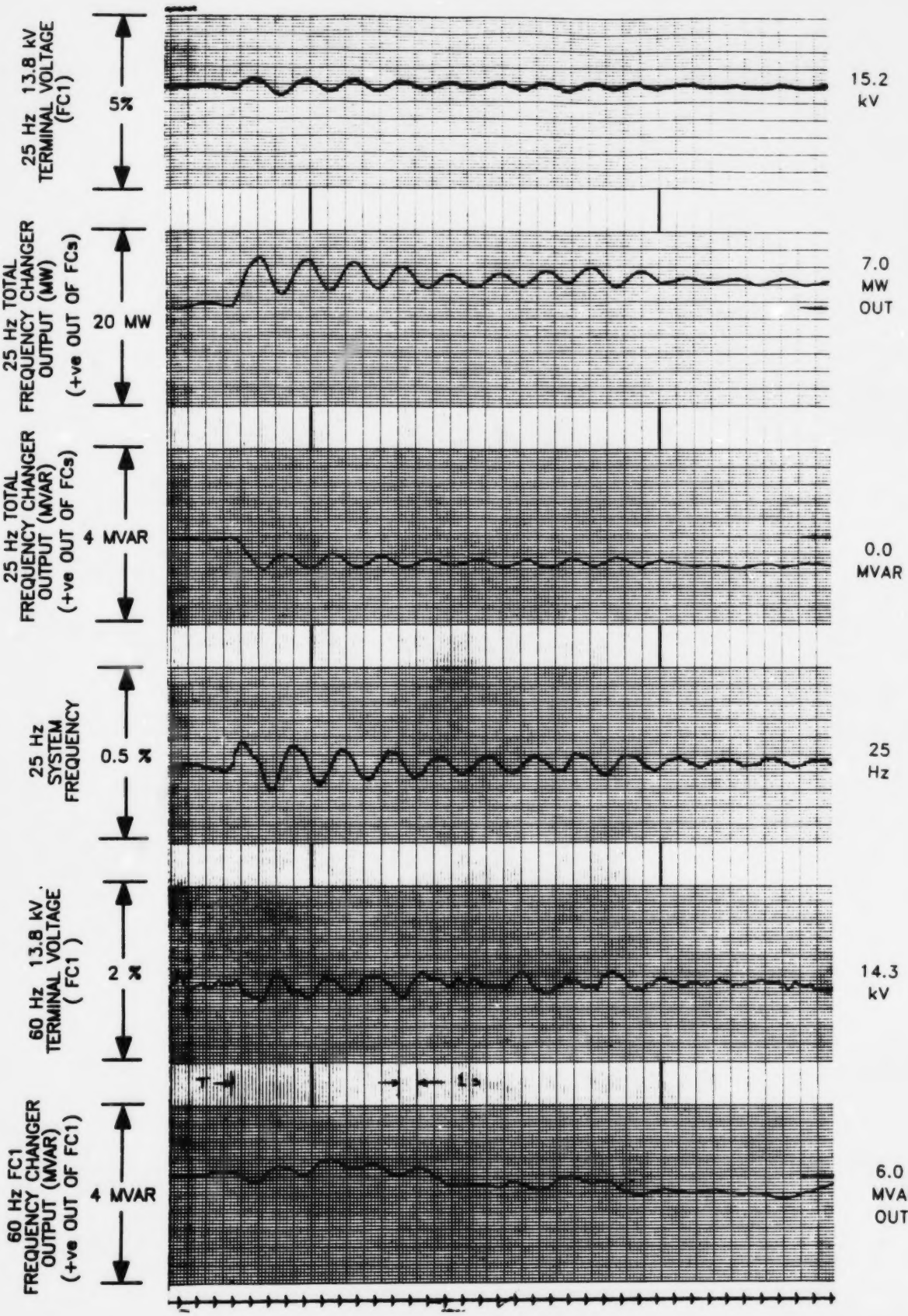

25 Hz 13.8 kV TERMINAL VOLTAGE (FC1)
5%
15.2 kV
25 Hz TOTAL FREQUENCY CHANGER OUTPUT (MW) (+ve OUT OF FCs)
20 MW
7.0 MW OUT
25 Hz TOTAL FREQUENCY CHANGER OUTPUT (MVAR) (+ve OUT OF FCs)
4 MVAR
0.0 MVAR
25 Hz SYSTEM FREQUENCY
0.5 %
25 Hz
60 Hz 13.8 kV TERMINAL VOLTAGE (FC1)
2 %
14.3 kV
60 Hz FC1 FREQUENCY CHANGER OUTPUT (MVAR) (+ve OUT OF FC1)
4 MVAR
6.0 MVAR OUT

FIGURE 5a : MARTINDALE TS/FC

TEST D2b REPEATED – CIRCUIT K1Z O/S, MARTINDALE FC1,FC7 I/S
ALL WAWAITIN UNITS I/S, CANYON G1 CONDENSING, TRIP WAWAITIN G1

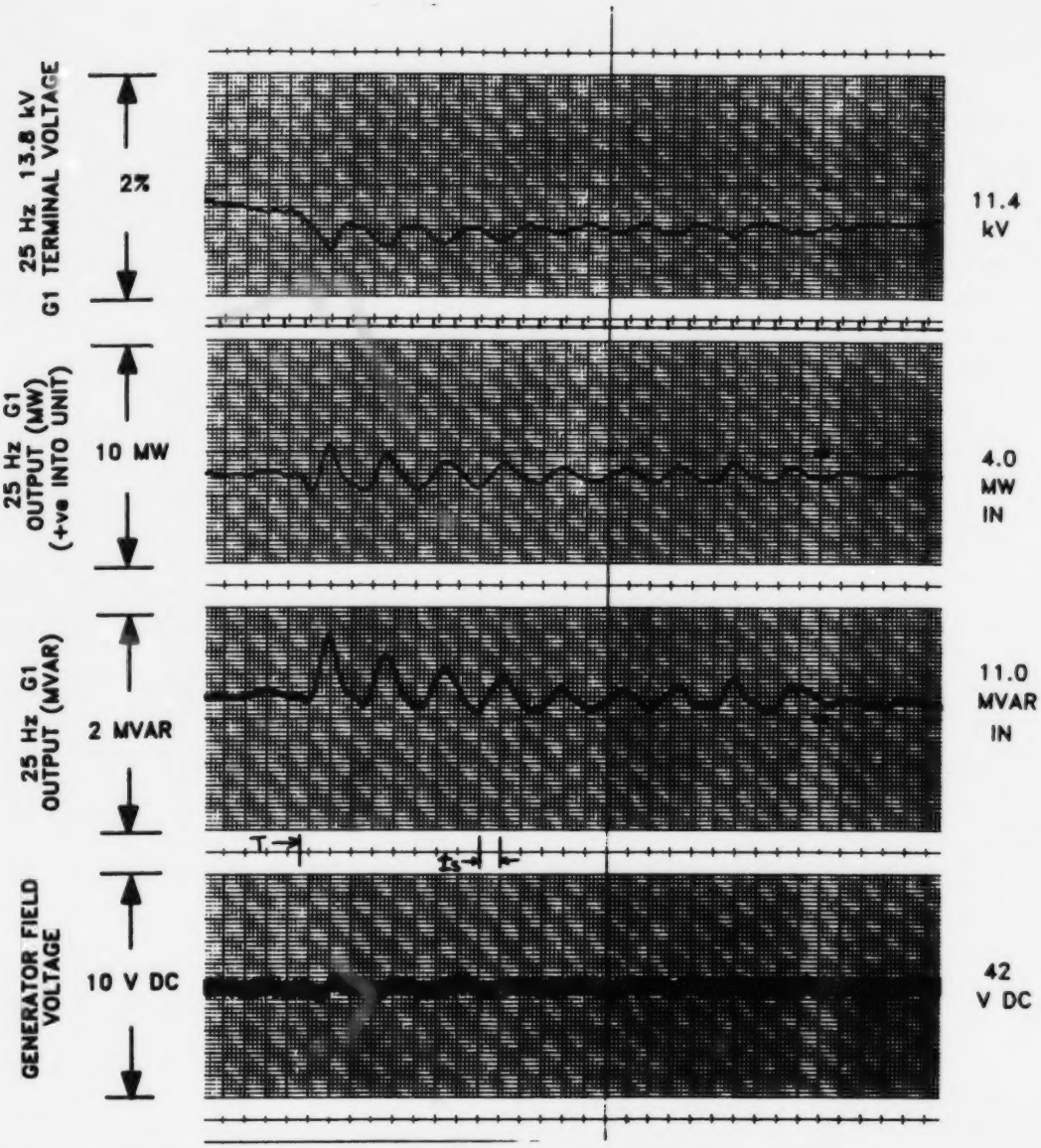


FIGURE 5b : ABITIBI CANYON GS

TEST D2B REPEATED – CIRCUIT K1Z O/S, MARTINDALE FC1, FC7 I/S
ALL WAWAITIN UNITS I/S, CANYON G1 CONDENSING, TRIP WAWAITIN G1

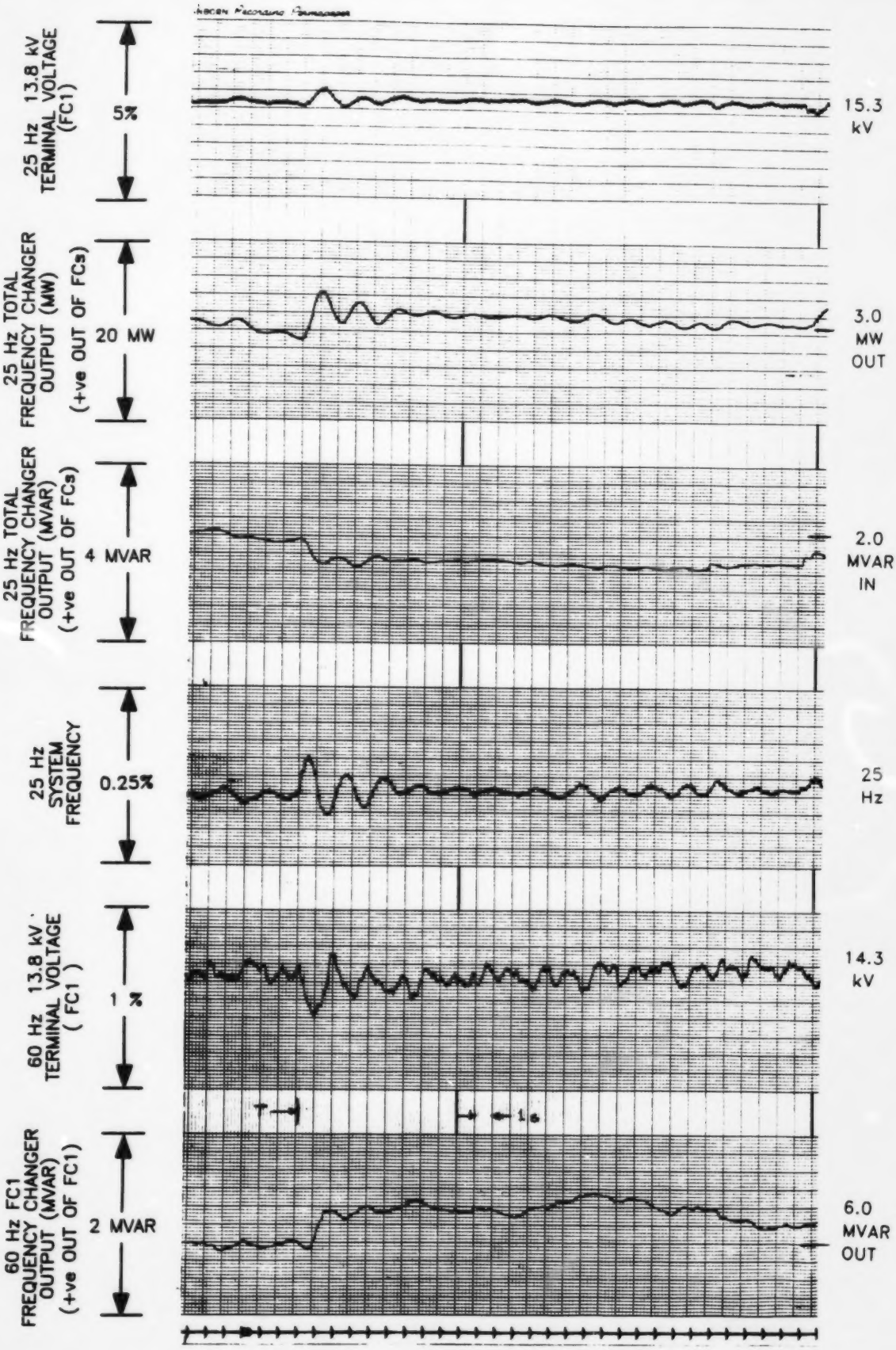


FIGURE 6a : MARTINDALE TS/FC
TEST D2C – CIRCUIT K1Z O/S, MARTINDALE FC1,FC7 I/S
WAWAITIN G2 OFF-LINE, CANYON G1 OFF-LINE, TRIP WAWAITIN G1

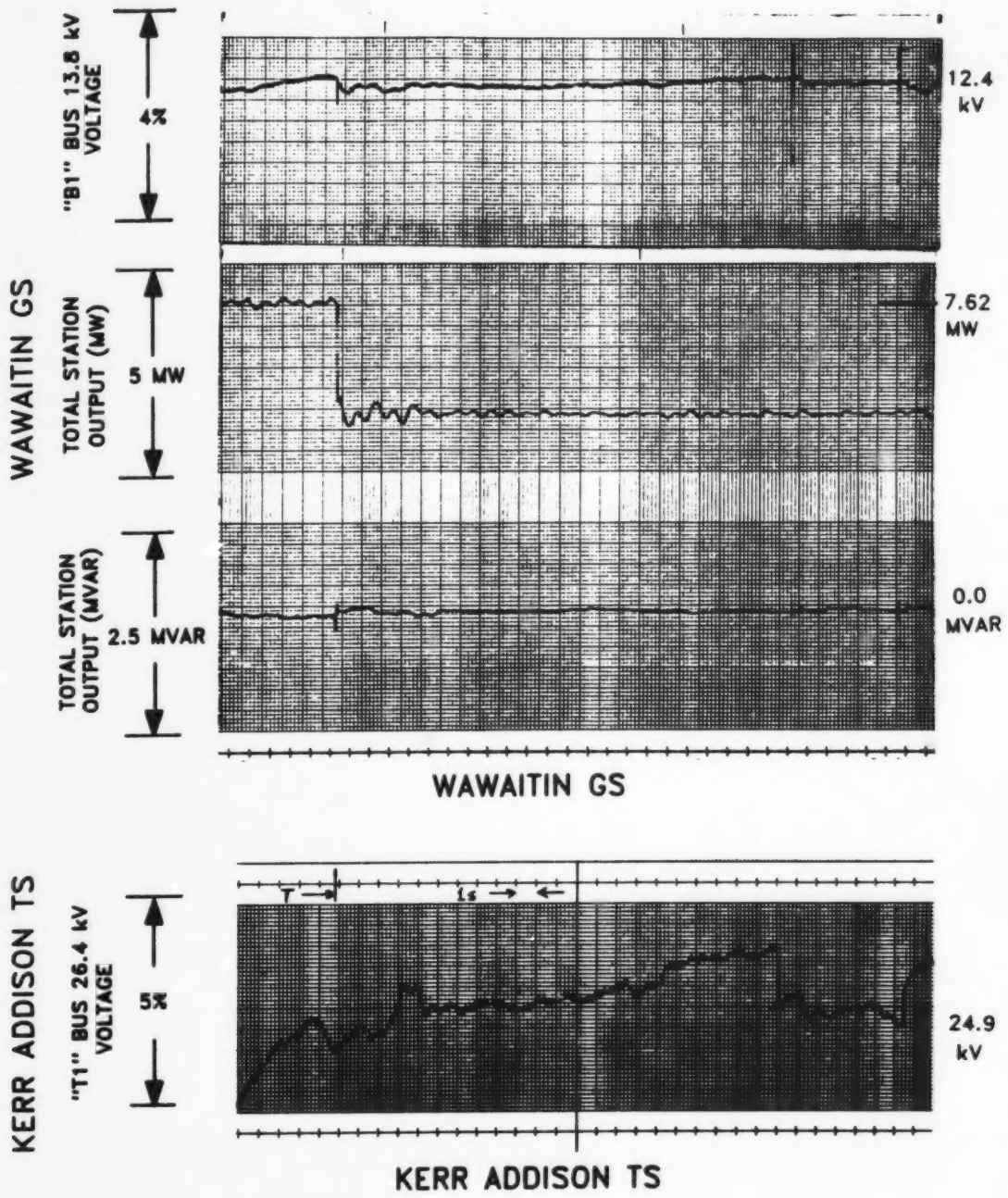


FIGURE 6b : WAWAITIN GS, KERR ADDISON TS

TEST D2C – CIRCUIT K1Z O/S, MARTINDALE FC1, FC7 I/S
WAWAITIN G2 OFF-LINE, CANYON G1 OFF-LINE, TRIP WAWAITIN G1

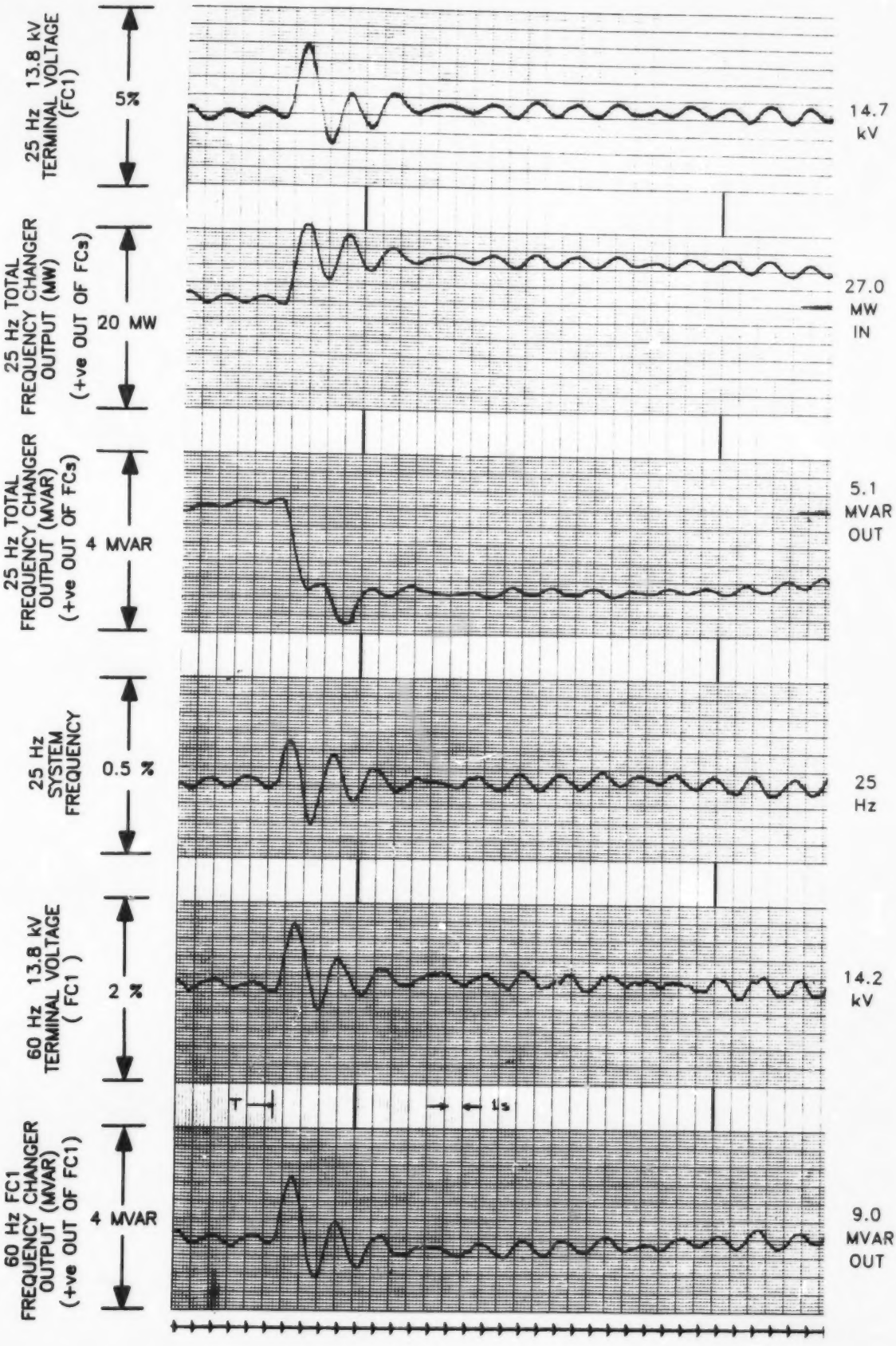

25 Hz 13.8 kV TERMINAL VOLTAGE (FC1)
5%
14.7 kV
25 Hz TOTAL FREQUENCY CHANGER OUTPUT (MW) (+ve OUT OF FCs)
20 MW
27.0 MW IN
25 Hz TOTAL FREQUENCY CHANGER OUTPUT (MVAR) (+ve OUT OF FCs)
4 MVAR
5.1 MVAR OUT
25 Hz SYSTEM FREQUENCY
0.5 %
25 Hz
60 Hz 13.8 kV TERMINAL VOLTAGE (FC1)
2 %
14.2 kV
T
1s
60 Hz FC1 FREQUENCY CHANGER OUTPUT (MVAR) (+ve OUT OF FC1)
4 MVAR
9.0 MVAR OUT

FIGURE 7a : MARTINDALE TS/FC

TEST D3 – CIRCUIT K1Z O/S, MARTINDALE FC1,FC7 I/S, ALL WAWAITIN UNITS I/S, CANYON G1 I/S, TRIP WAWAITIN G1 & G2

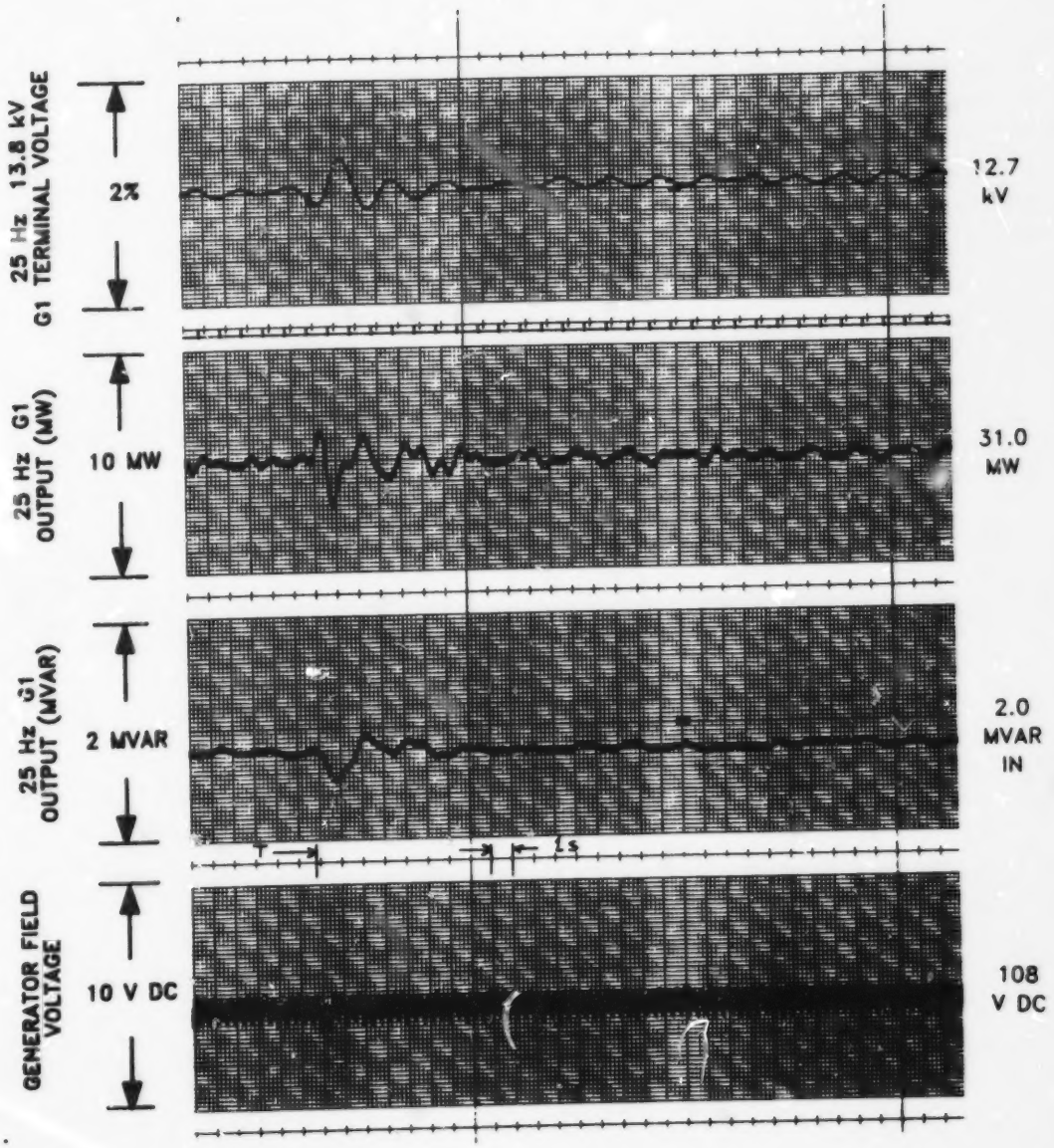


FIGURE 7b : ABITIBI CANYON GS

TEST D3 – CIRCUIT K1Z O/S, MARTINDALE FC1, FC7 I/S, ALL WAWAITIN UNITS I/S, CANYON G1 I/S, TRIP WAWAITIN G1, G2

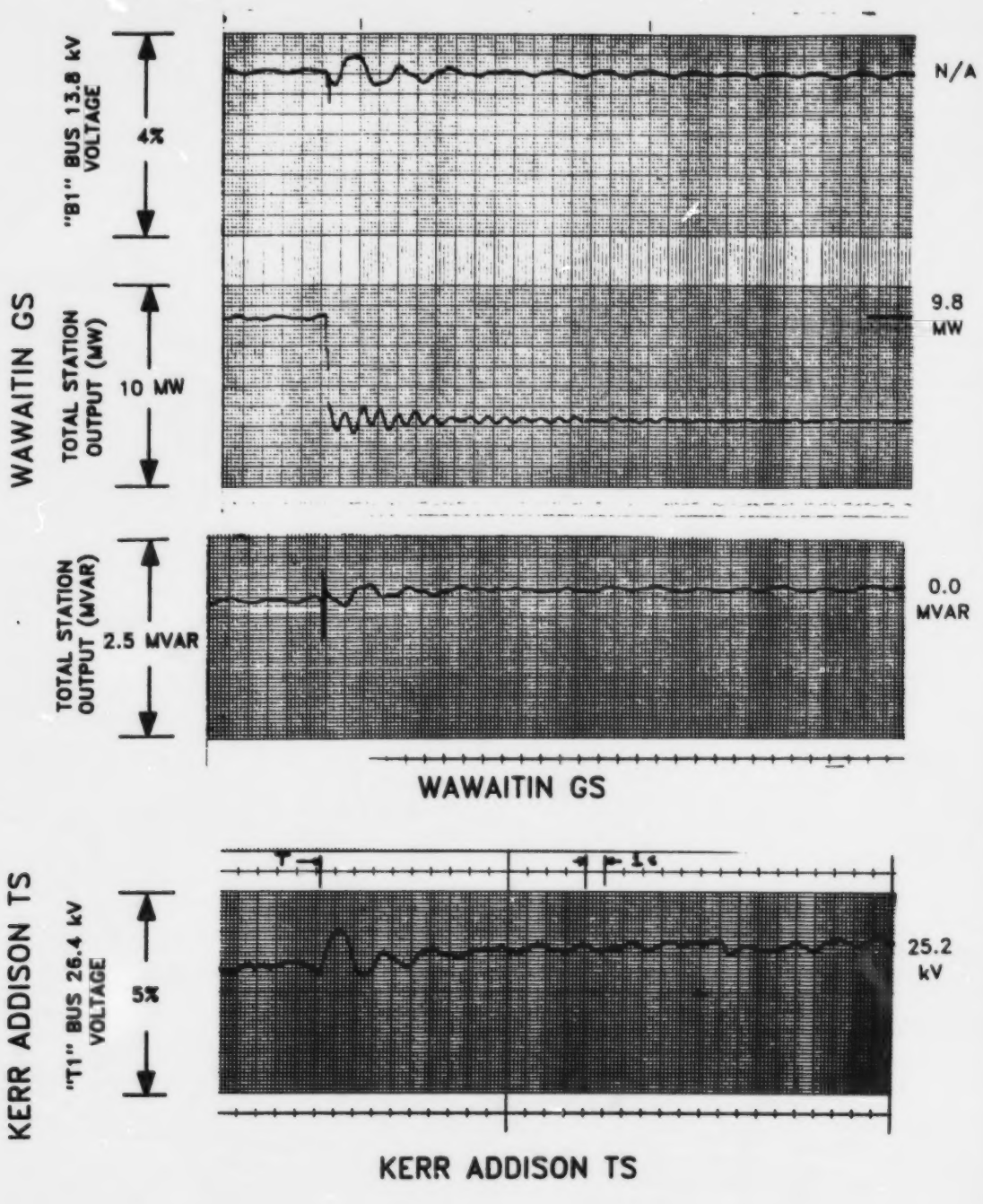


FIGURE 7c : WAWAITIN GS, KERR ADDISON TS

TEST D3 – CIRCUIT K1Z O/S, MARTINDALE FC1, FC7 I/S, ALL WAWAITIN UNITS I/S, CANYON G1 I/S, TRIP WAWAITIN G1 & G2

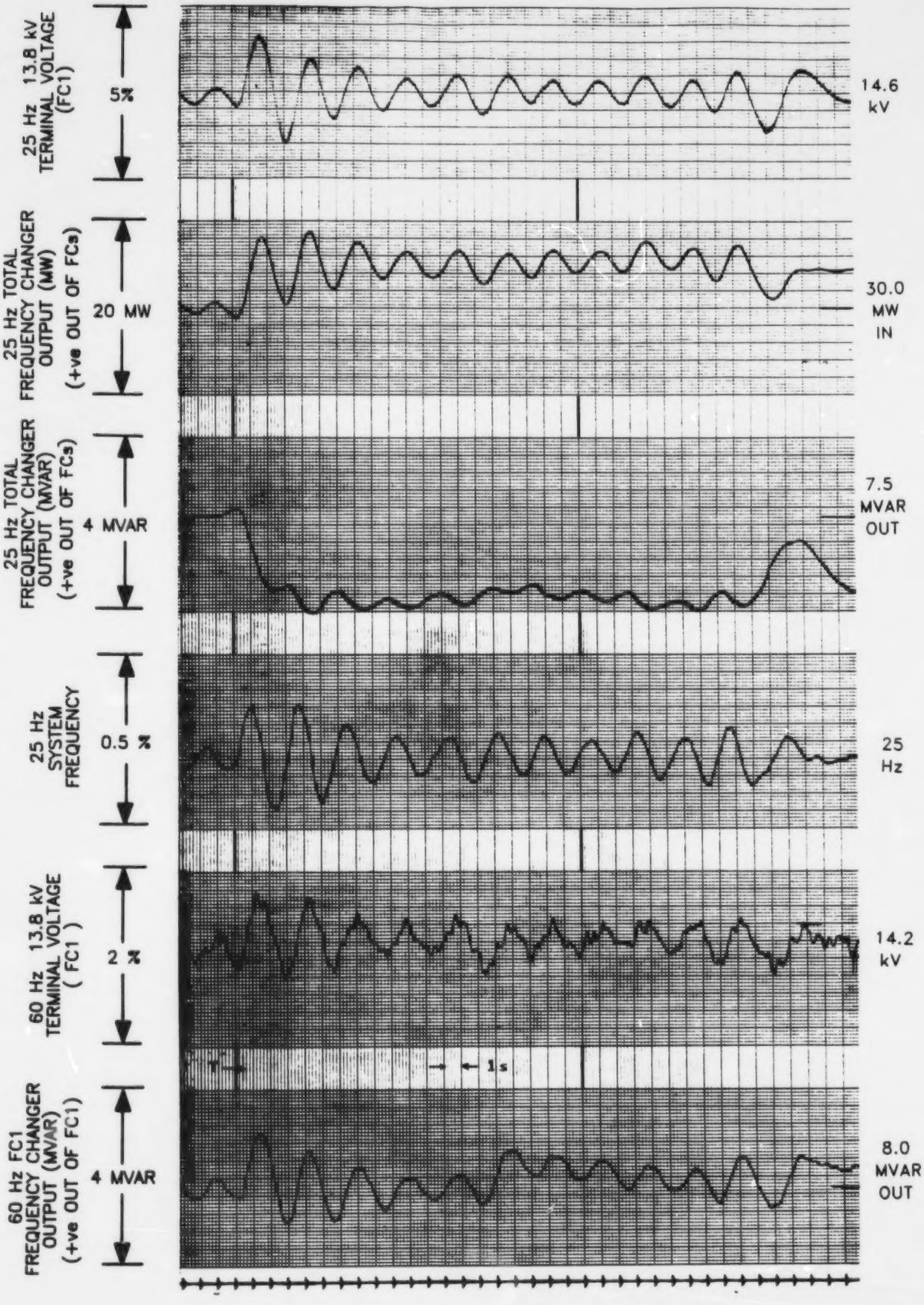

25 Hz 13.8 kV TERMINAL VOLTAGE (FC1)
5%
14.6 kV
25 Hz TOTAL FREQUENCY CHANGER OUTPUT (MW) (+ve OUT OF FCs)
20 MW
30.0 MW IN
25 Hz TOTAL FREQUENCY CHANGER OUTPUT (MVAR) (+ve OUT OF FCs)
4 MVAR
7.5 MVAR OUT
25 Hz SYSTEM FREQUENCY
0.5 %
25 Hz
60 Hz 13.8 kV TERMINAL VOLTAGE (FC1)
2 %
14.2 kV
1s
60 Hz FC1 FREQUENCY CHANGER OUTPUT (MVAR) (+ve OUT OF FC1)
4 MVAR
8.0 MVAR OUT

FIGURE 8a : MARTINDALE TS/FC
TEST D4 – CIRCUIT K1Z O/S, MARTINDALE FC1 I/S FC6 & FC7 O/S
ALL WAWAITIN UNITS I/S, CANYON G1 I/S, TRIP WAWAITIN G1 & G2

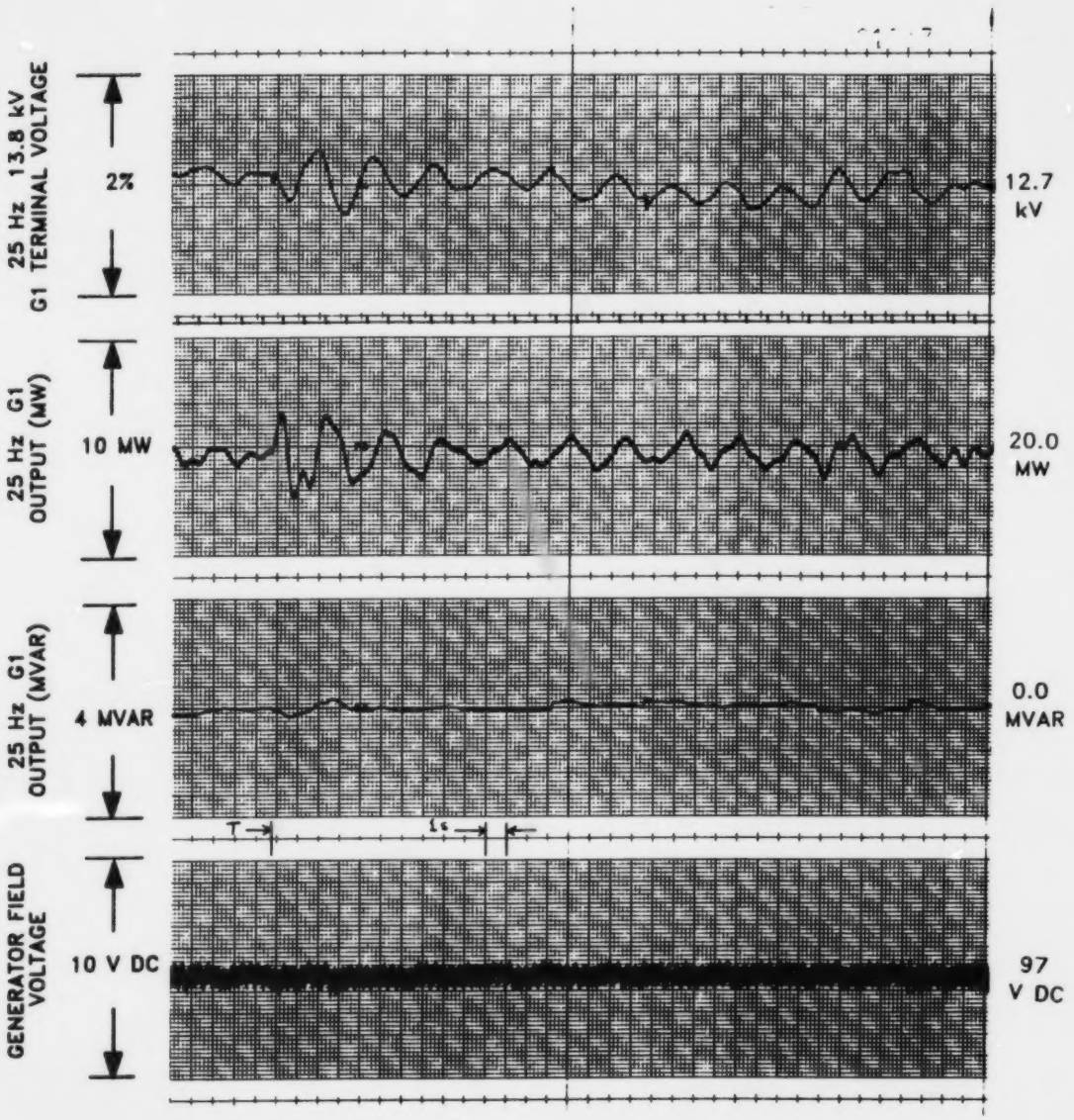


FIGURE 8b : ABITIBI CANYON GS

TEST D4 – CIRCUIT K1Z O/S, MARTINDALE FC1 I/S, FC6 & FC7 O/S
WAWAITIN UNITS I/S, CANYON G1 I/S, TRIP WAWAITIN G1, G2

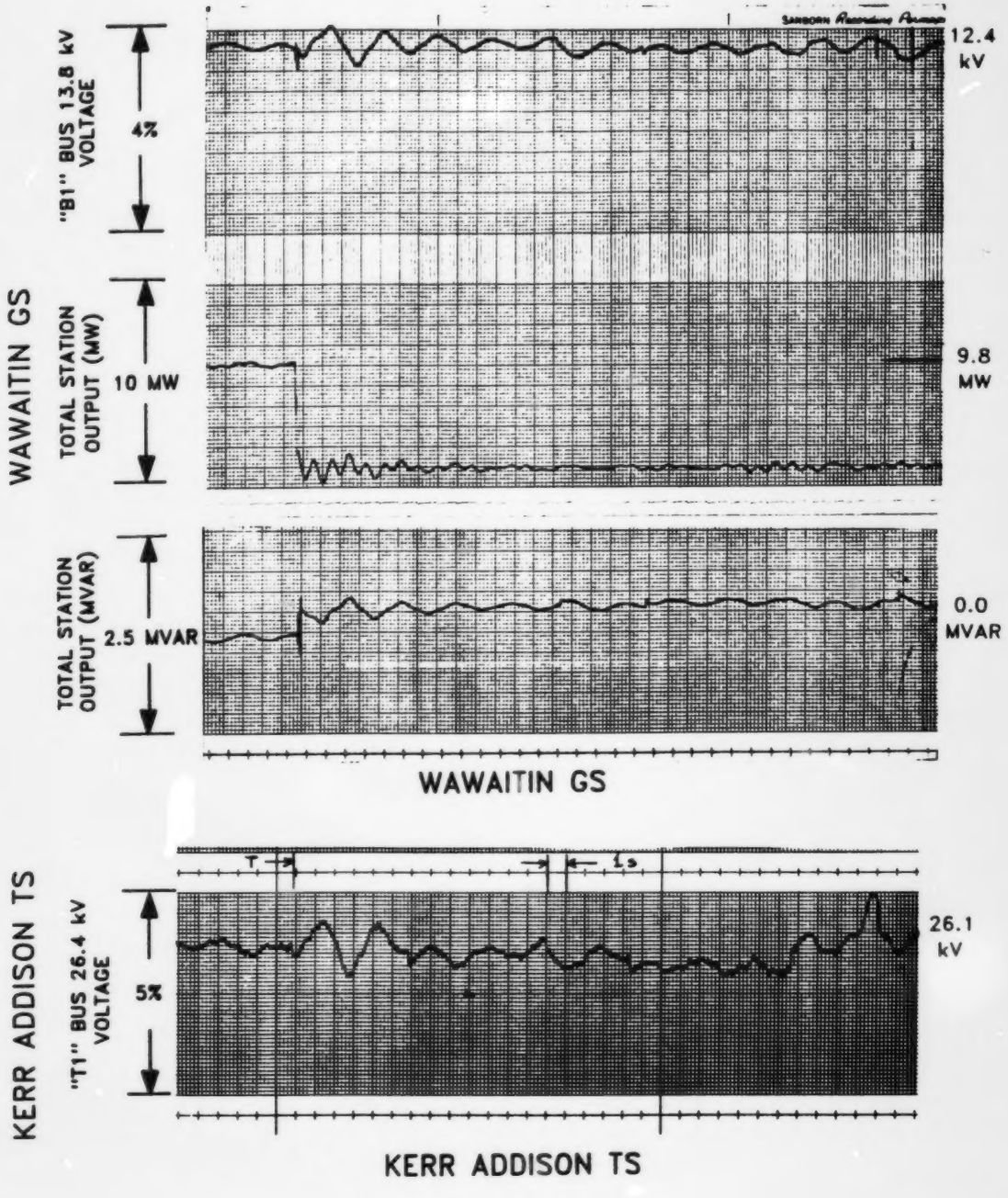


FIGURE 8c : WAWAITIN GS, KERR ADDISON TS

TEST D4 – CIRCUIT K1Z O/S, MARTINDALE FC1 I/S, FC6 & FC7 O/S
WAWAITIN UNITS I/S, CANYON G1 I/S, TRIP WAWAITIN G1 & G2

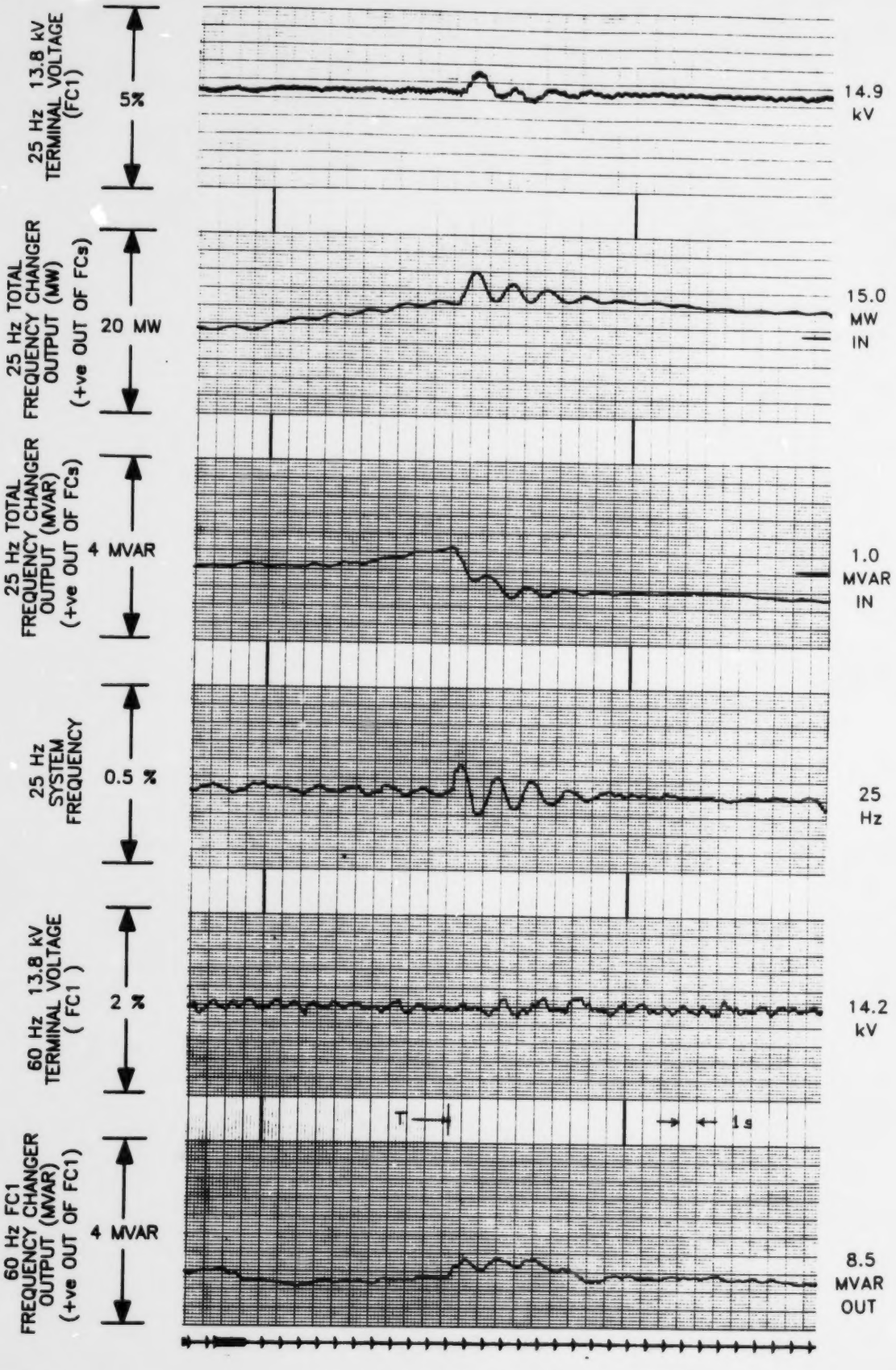

25 Hz 13.8 kV TERMINAL VOLTAGE (FC1)
5%
14.9 kV
25 Hz TOTAL FREQUENCY CHANGER OUTPUT (MW) (+ve OUT OF FCs)
20 MW
15.0 MW IN
25 Hz TOTAL FREQUENCY CHANGER OUTPUT (MVAR) (+ve OUT OF FCs)
4 MVAR
1.0 MVAR IN
25 Hz SYSTEM FREQUENCY
0.5 %
25 Hz
60 Hz 13.8 kV TERMINAL VOLTAGE (FC1)
2 %
14.2 kV
T
1s
60 Hz FC1 FREQUENCY CHANGER OUTPUT (MVAR) (+ve OUT OF FC1)
4 MVAR
8.5 MVAR OUT

FIGURE 9a : MARTINDALE TS/FC
TEST D5 – CIRCUIT K1Z O/S, MARTINDALE FC1 & FC7 I/S, TIMMINS BREAKER 19M1T OPEN, ALL WAWAITIN UNITS I/S, TRIP WAWAITIN G1

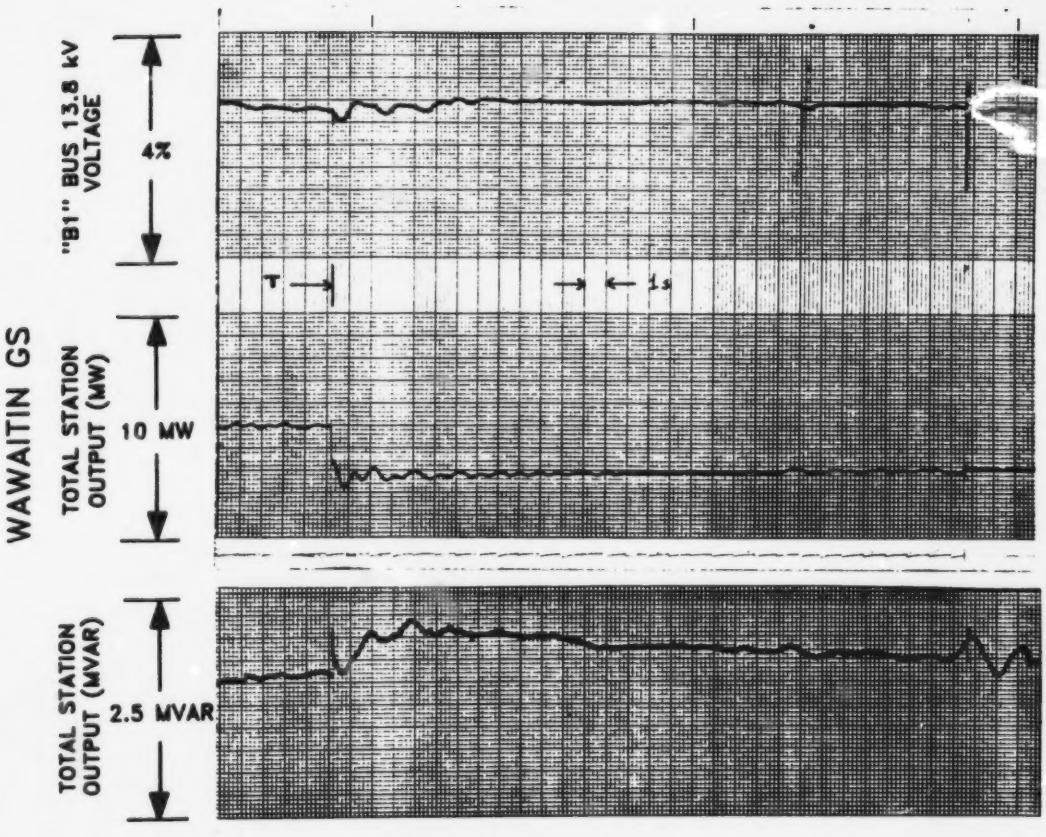


FIGURE 9b : WAWAITIN GS

TEST D5 – CIRCUIT K1Z O/S, MARTINDALE FC1, FC7 I/S, TIMMINS BREAKER 19M1T OPEN, ALL WAWAITIN UNITS I/S, TRIP WAWAITIN G1

(INITIAL CONDITIONS NOT LISTED)

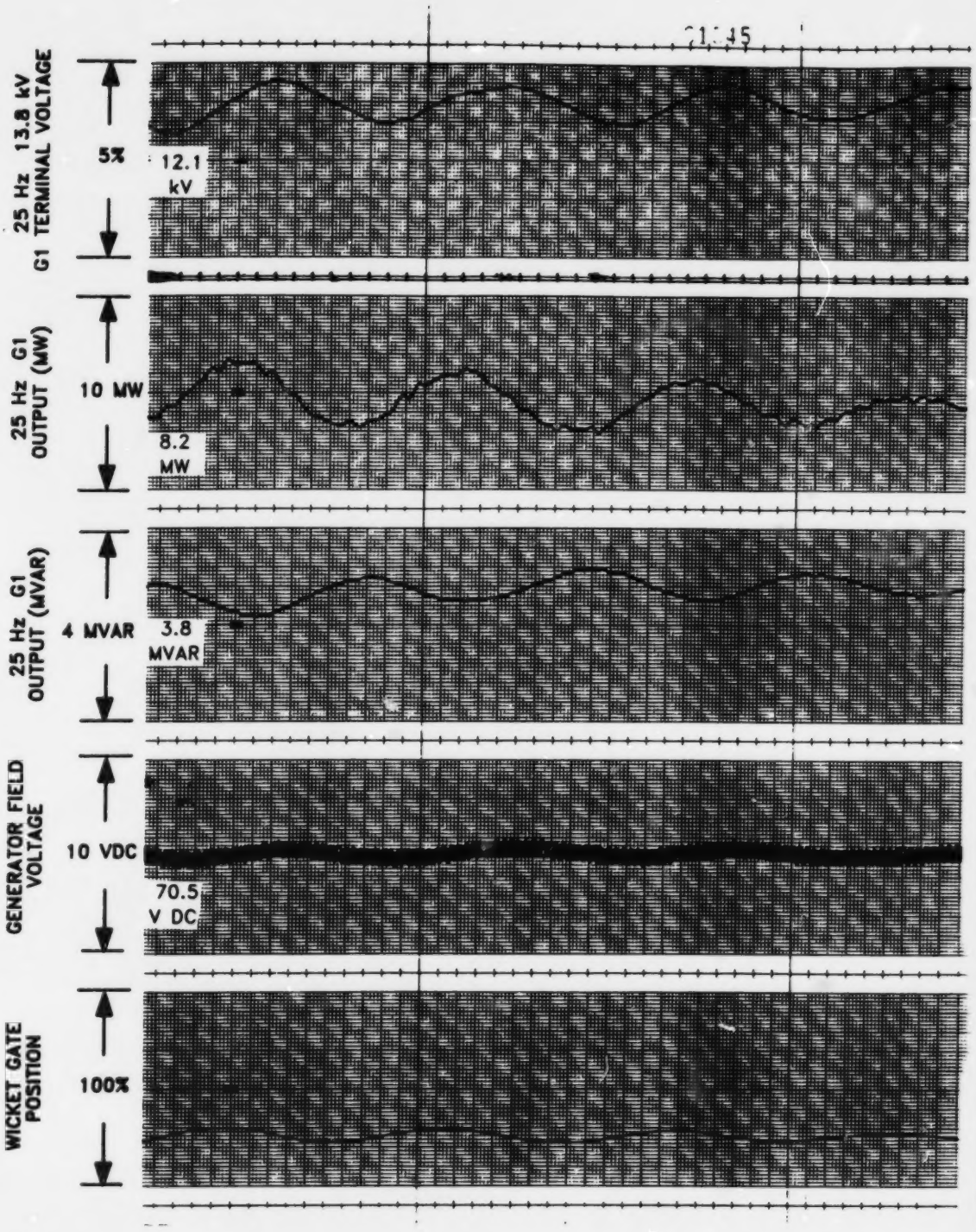


FIGURE 10 : ABITIBI CANYON GS

MONITORING OF LOW FREQUENCY OSCILLATIONS WITH 25 Hz SYSTEM ISLANDED – K1Z O/S, COPPER CLIFF BREAKER 10S1R OPEN ALL WAWAITIN GENERATING UNITS O/S

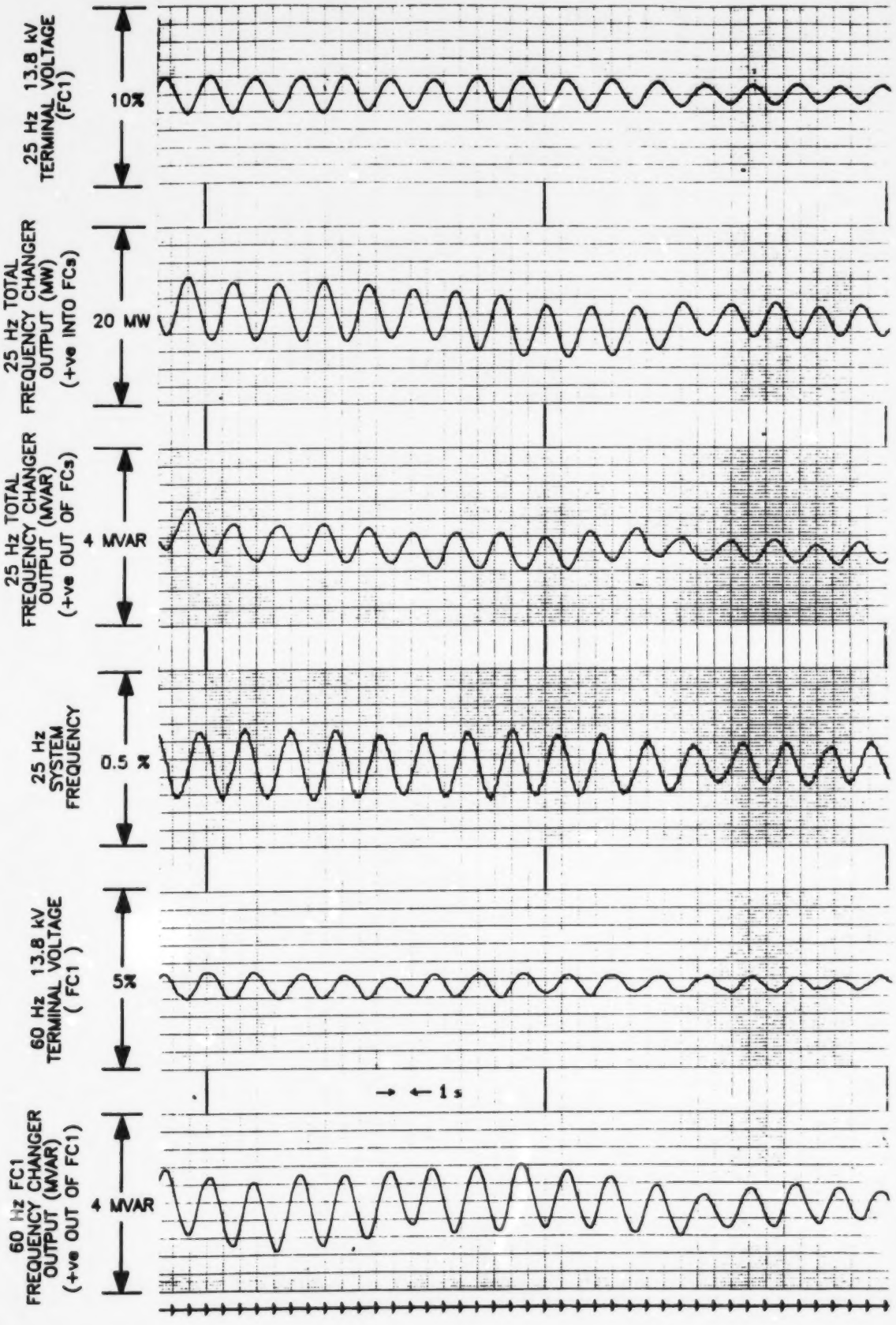

25 Hz 13.8 kV TERMINAL VOLTAGE (FC1)
10%
25 Hz TOTAL FREQUENCY CHANGER OUTPUT (MW) (+ve INTO FCs)
20 MW
25 Hz TOTAL FREQUENCY CHANGER OUTPUT (MVAR) (+ve OUT OF FCs)
4 MVAR
25 Hz SYSTEM FREQUENCY
0.5 %
60 Hz 13.8 kV TERMINAL VOLTAGE (FC1)
5%
→ ← 1 s
60 Hz FC1 FREQUENCY CHANGER OUTPUT (MVAR) (+ve OUT OF FC1)
4 MVAR

FIGURE 11 : MARTINDALE TS/FC
MONITORING OF QUANTITIES ON MAY 19, 1988. K1Z I/S
MARTINDALE FC1 & FC7 I/S. CANYON G1 GENERATING

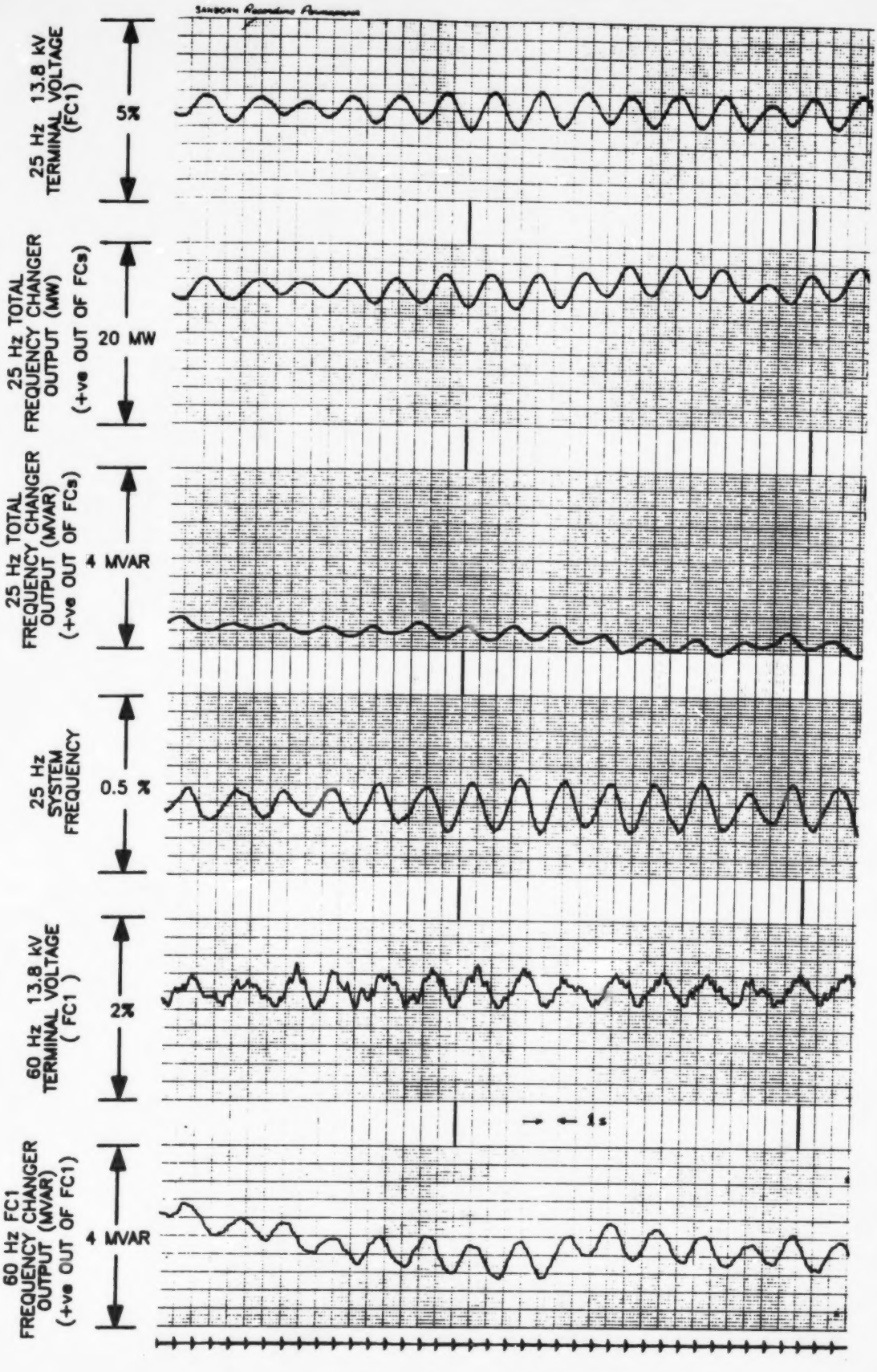


FIGURE 12a : MARTINDALE TS/FC
MONITORING FOLLOWING TEST D4 – K1Z O/S, MARTINDALE FC1 I/S
FC6 & FC7 O/S. ALL WAWAITIN UNITS I/S. CANYON G1 I/S

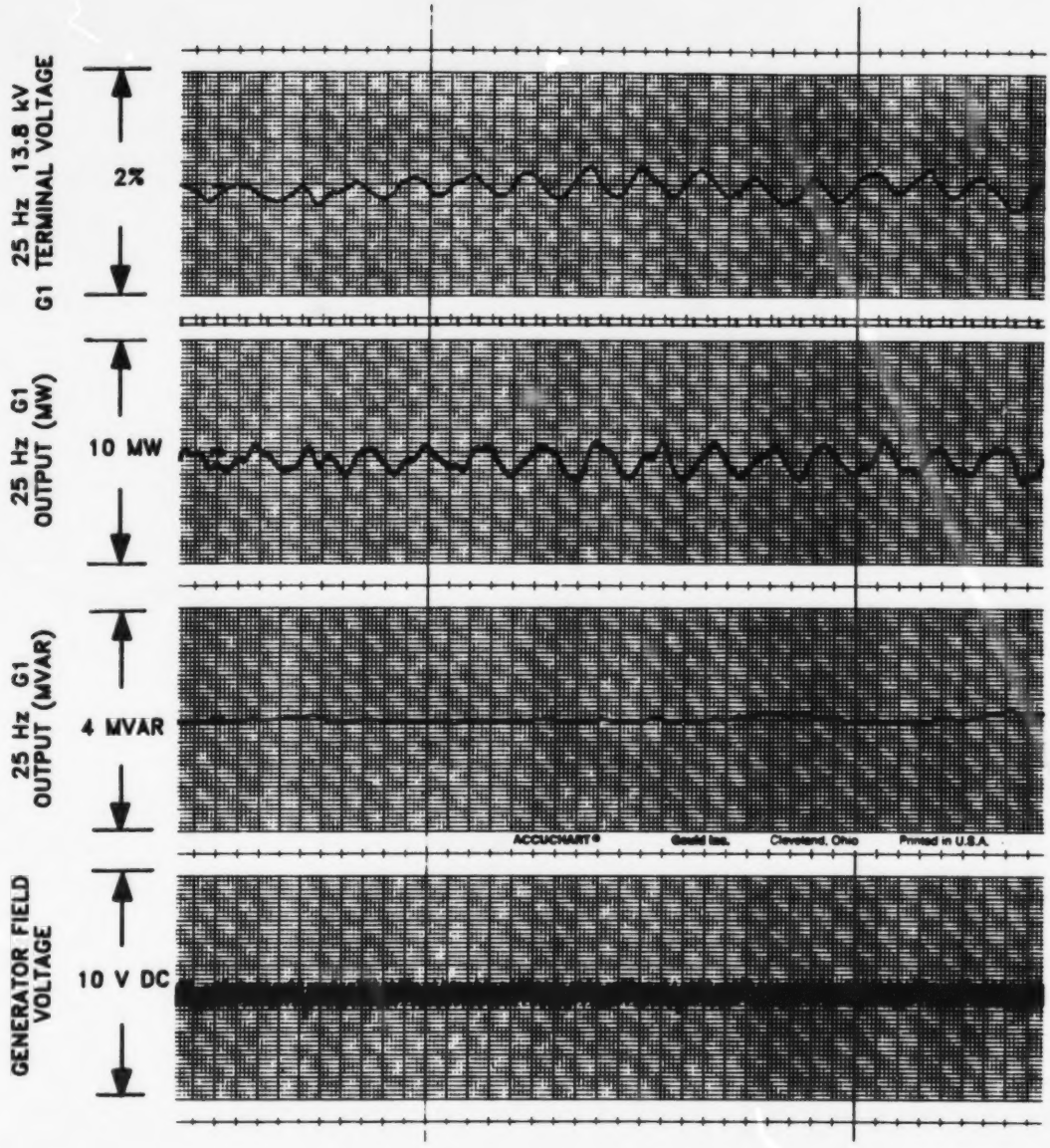


FIGURE 12b : ABITIBI CANYON GS

MONITORING FOLLOWING TEST D4 – K1Z O/S, MARTINDALE FC1 I/S
FC6 & FC7 O/S. ALL WAWAITIN UNITS I/S, CANYON G1 I/S

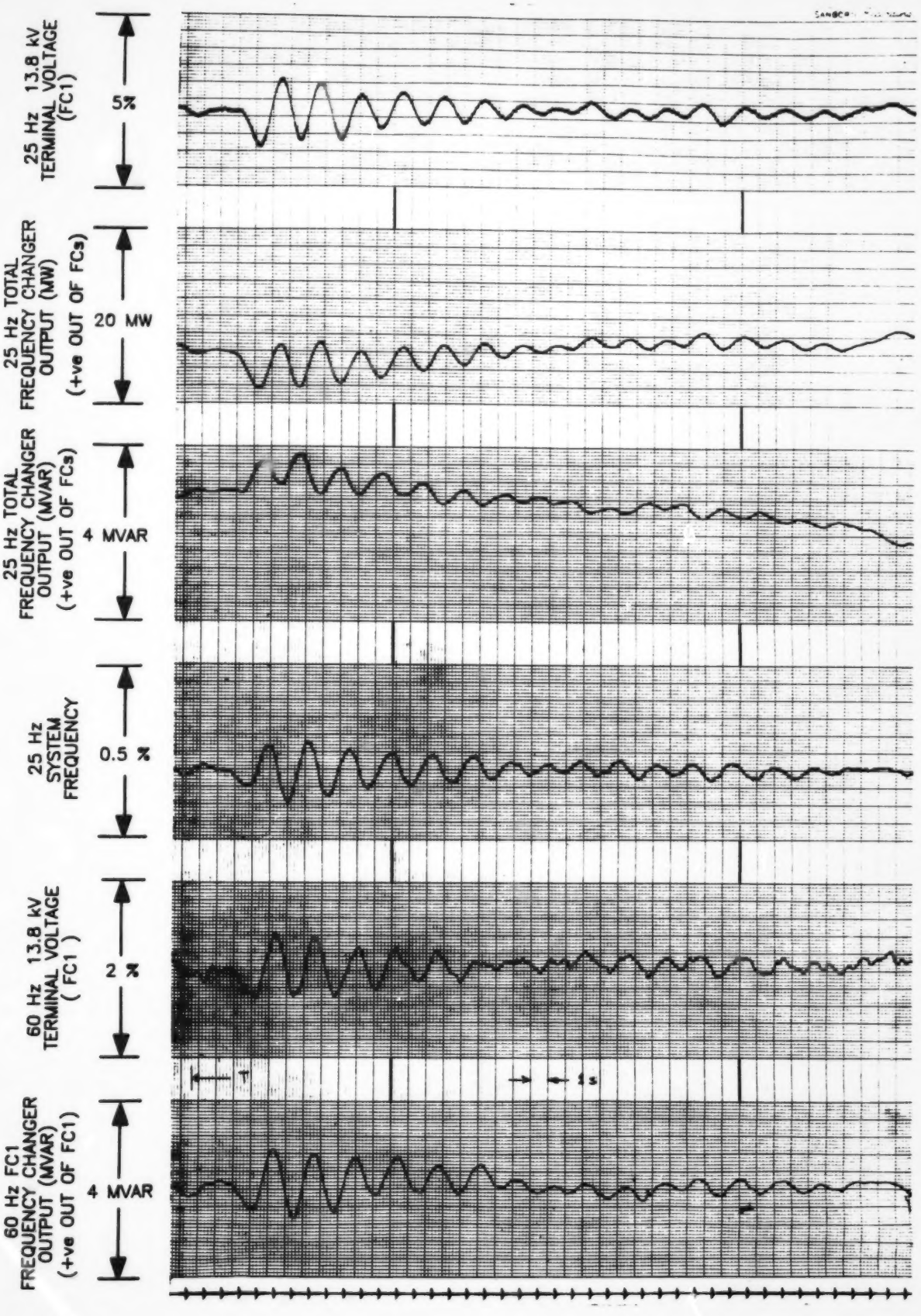

25 Hz 13.8 kV TERMINAL VOLTAGE (FC1)
5%
25 Hz TOTAL FREQUENCY CHANGER OUTPUT (MW) (+ve OUT OF FCs)
20 MW
25 Hz TOTAL FREQUENCY CHANGER OUTPUT (MVAR) (+ve OUT OF FCs)
4 MVAR
25 Hz SYSTEM FREQUENCY
0.5 %
60 Hz 13.8 kV TERMINAL VOLTAGE (FC1)
2 %
60 Hz FC1 FREQUENCY CHANGER OUTPUT (MVAR) (+ve OUT OF FC1)
4 MVAR
T
1s

FIGURE 13a : MARTINDALE TS/FC
MONITORING DURING CUSTOMER LOAD VARIATIONS – CIRCUIT K1Z O/S
MARTINDALE FC1 & FC7 I/S, WAWAITIN G2 O/S

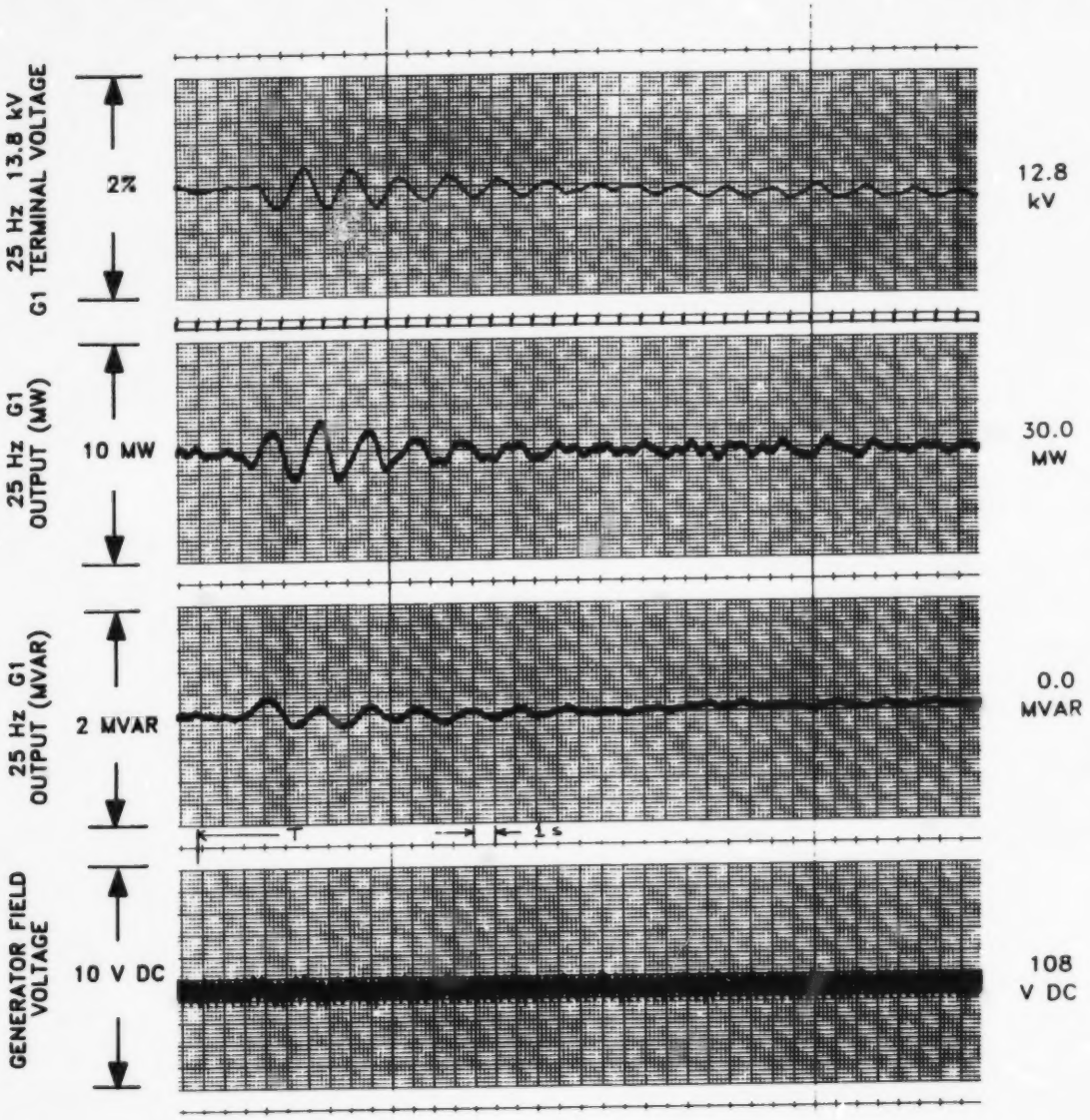


FIGURE 13b : ABITIBI CANYON GS

MONITORING DURING CUSTOMER LOAD VARIATIONS – CIRCUIT K1Z O/S
MARTINDALE FC1 & FC7 I/S, WAWAITIN G2 O/S

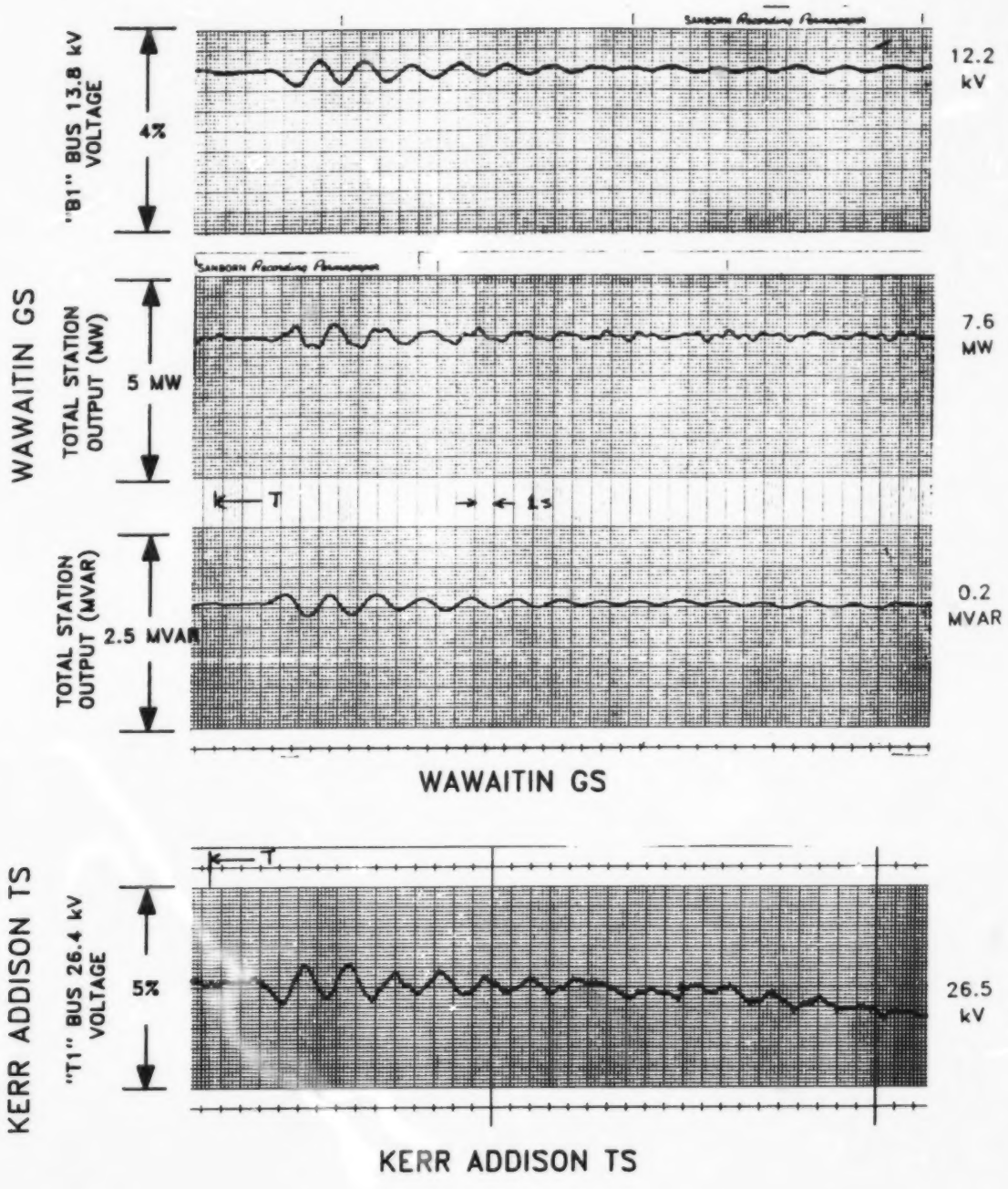


FIGURE 13c : WAWAITIN GS, KERR ADDISON TS

MONITORING DURING CUSTOMER LOAD VARIATIONS – CIRCUIT K1Z O/S
MARTINDALE FC1 & FC7 I/S, WAWAITIN G2 O/S

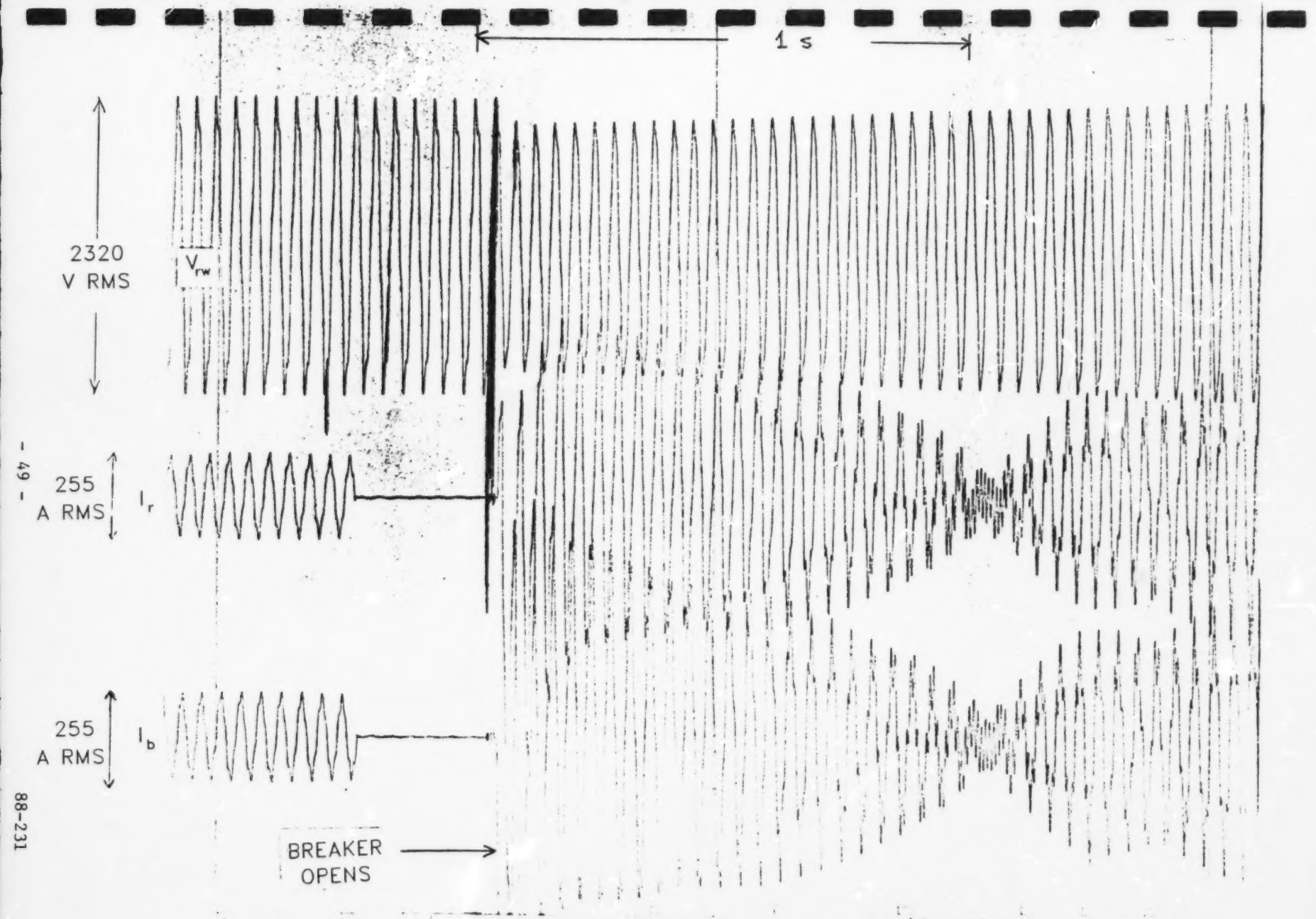


FIGURE 14: KERR ADDISON MINES HOIST MOTOR
AUTOTRANSFORMER SWITCHING

88-231

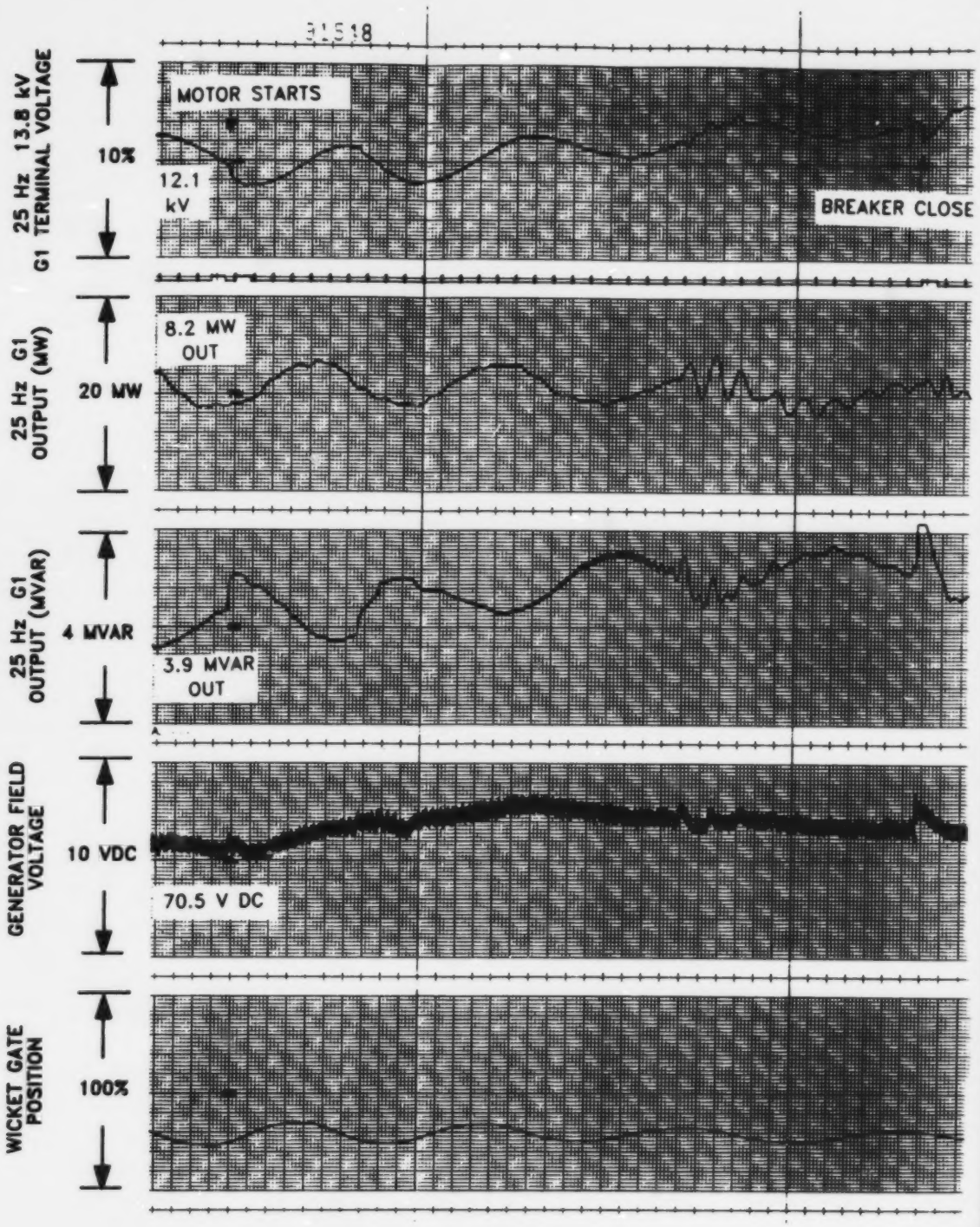
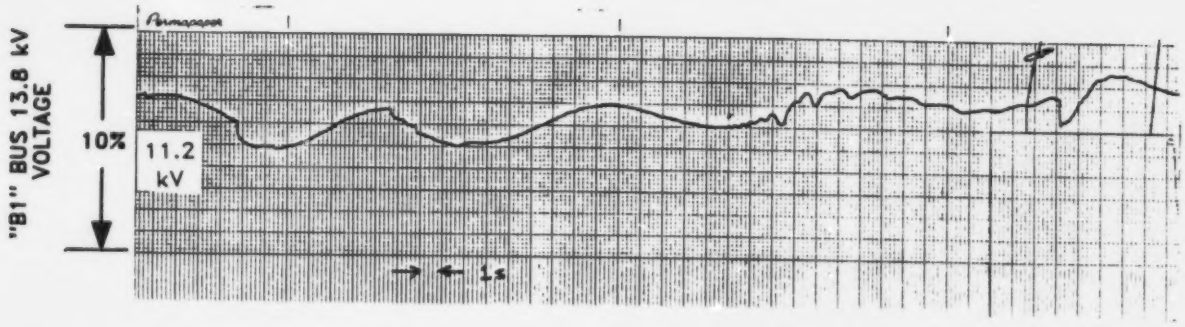
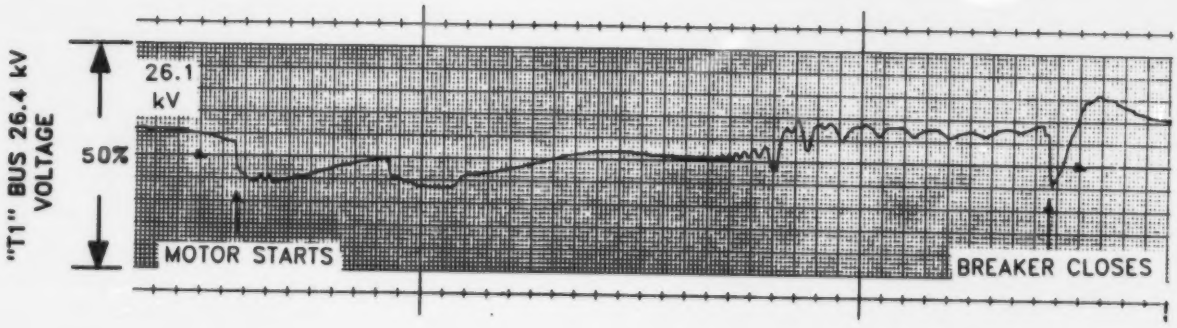


FIGURE 15a : ABITIBI CANYON GS

TEST M3 – CIRCUIT K1Z O/S, COPPER CLIFF TS 10S1R OPEN, CANYON G1 I/S, WAWAITIN UNITS O/S , START KERR ADDISON MOTOR



WAWAITIN GS



KERR ADDISON TS

FIGURE 15b : WAWAITIN GS, KERR ADDISON TS

TEST M3 – CIRCUIT K1Z O/S, COPPER CLIFF TS 10S1R OPEN, CANYON G1 I/S, ALL WAWAITIN UNITS O/S, START KERR ADDISON MOTOR

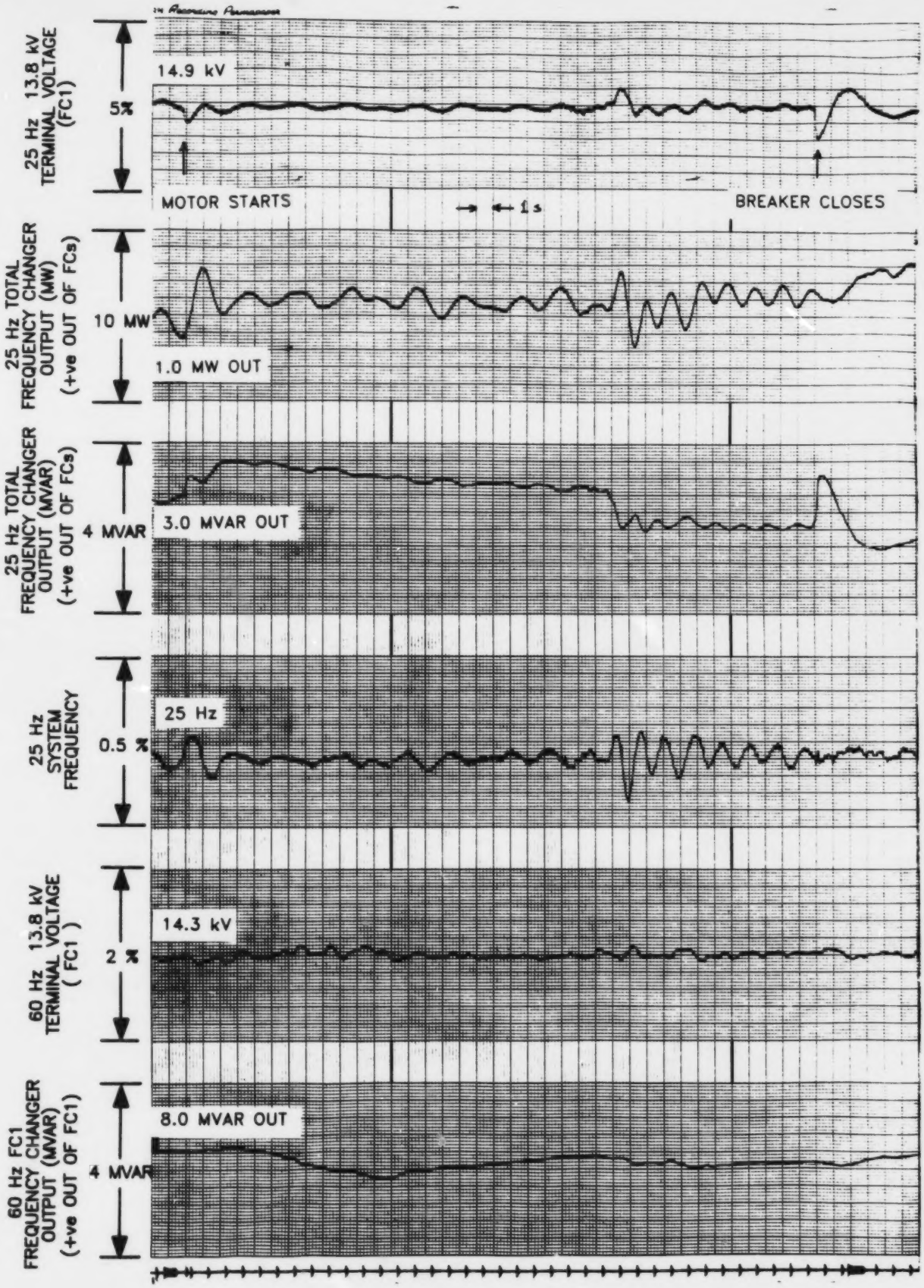
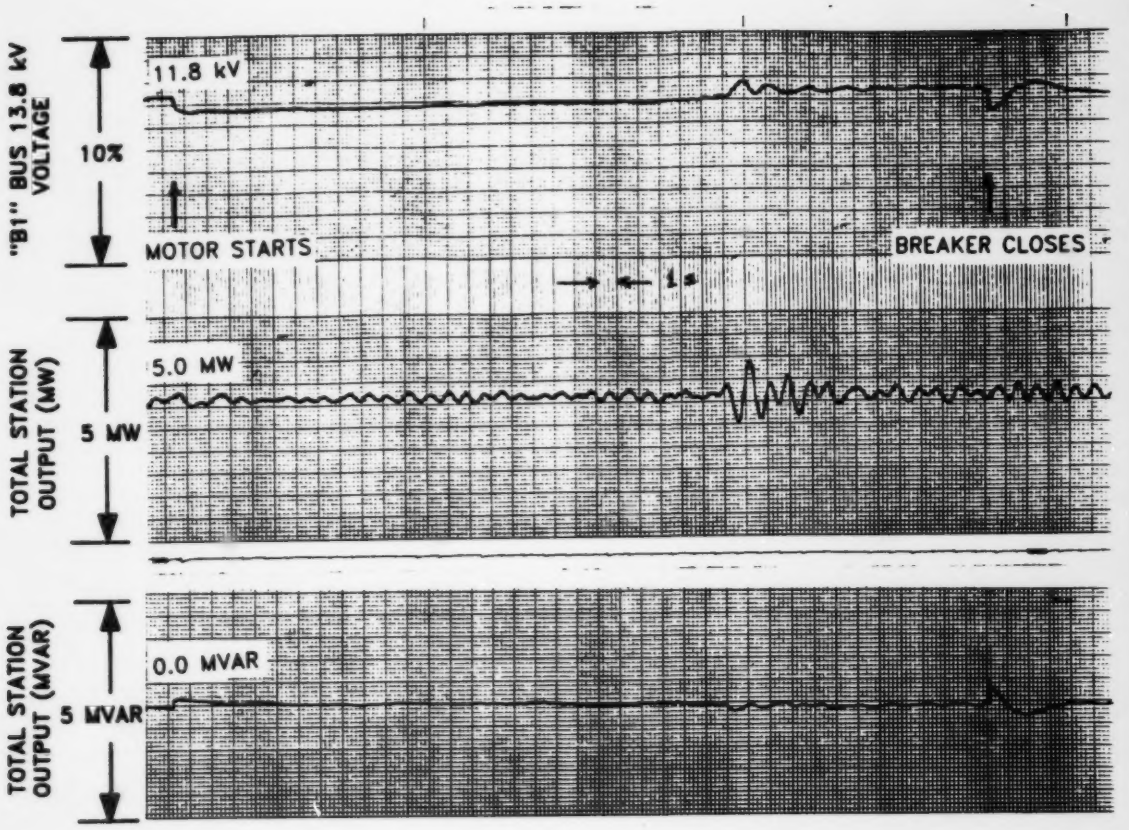
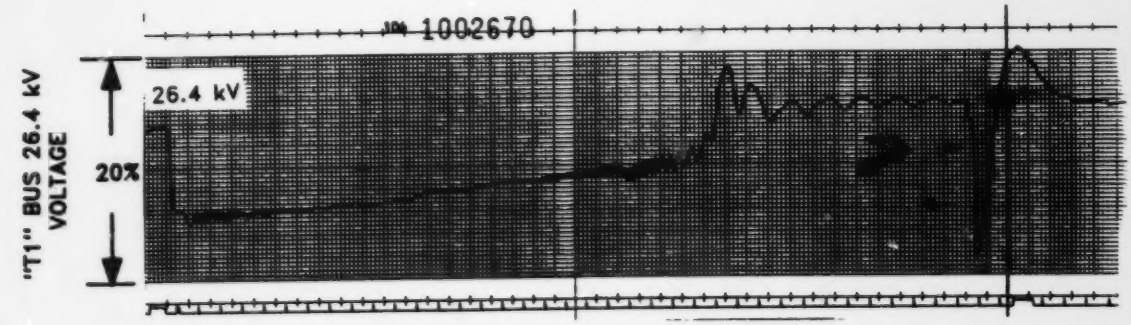


FIGURE 16a : MARTINDALE TS/FC

TEST M4 – CIRCUIT K1Z O/S, MARTINDALE FC1 & FC7 I/S, CANYON G1 O/S, WAWAITIN G3, G4 I/S, START KERR ADDISON MOTOR



WAWAITIN GS



KERR ADDISON TS

FIGURE 16b : WAWAITIN GS, KERR ADDISON TS

TEST M4 – CIRCUIT K1Z O/S, MARTINDALE FC1, FC7 I/S, CANYON G1 O/S, WAWAITIN G3 & G4 I/S, START KERR ADDISON MOTOR

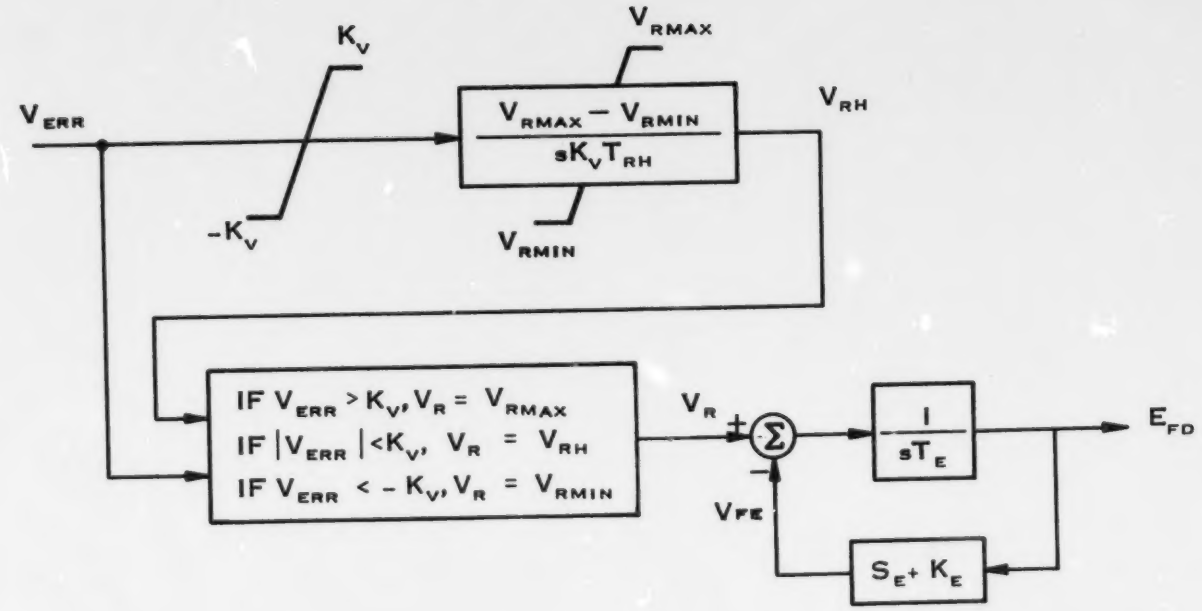


FIGURE 17

TYPE DC3 NON–CONTINUOUSLY ACTING REGULATORS

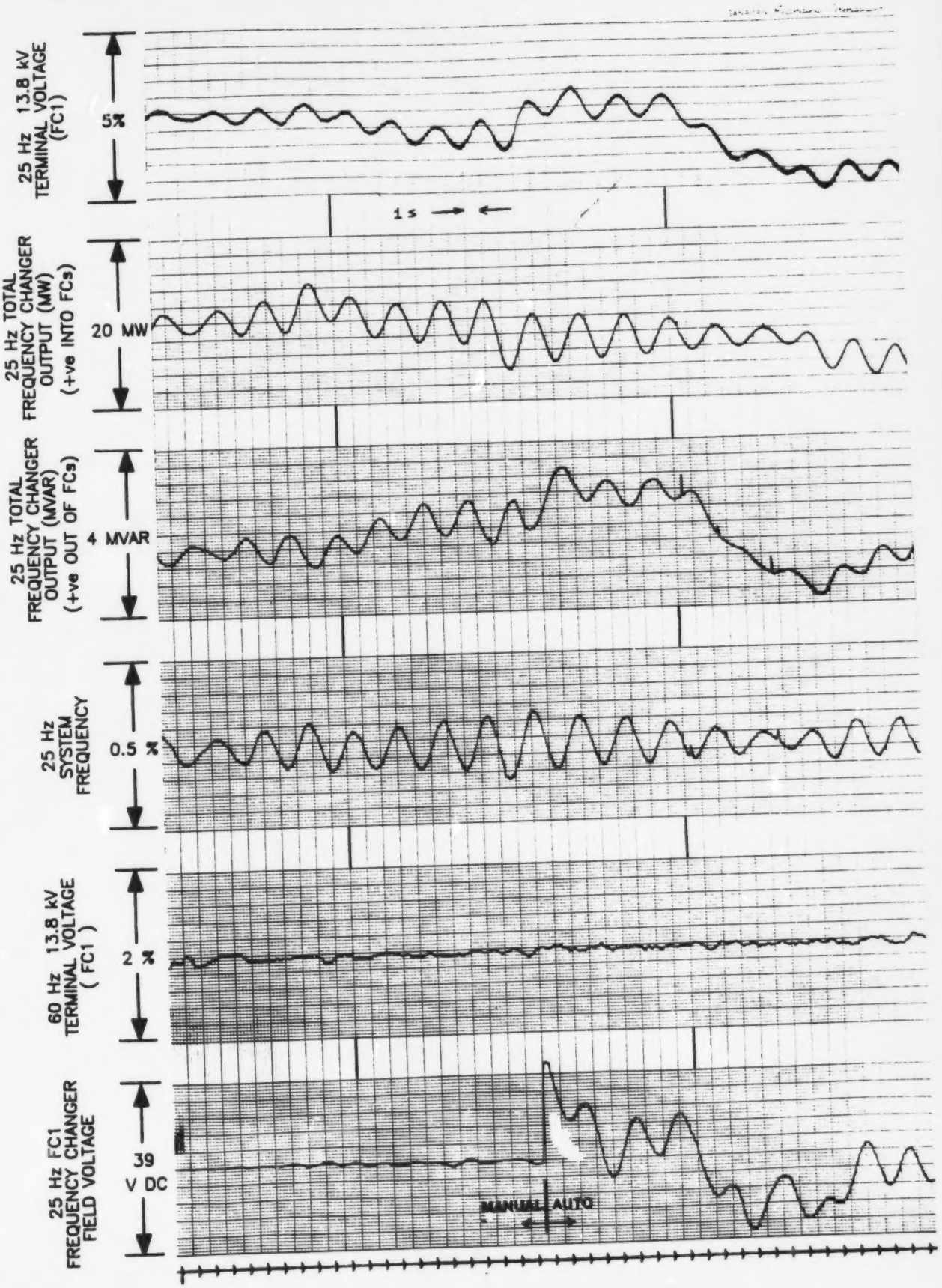

25 Hz 13.8 kV TERMINAL VOLTAGE (FC1)
5%
1s
25 Hz TOTAL FREQUENCY CHANGER OUTPUT (MW) (+ve INTO FCs)
20 MW
25 Hz TOTAL FREQUENCY CHANGER OUTPUT (MVAR) (+ve OUT OF FCs)
4 MVAR
25 Hz SYSTEM FREQUENCY
0.5 %
60 Hz 13.8 kV TERMINAL VOLTAGE (FC1)
2 %
25 Hz FC1 FREQUENCY CHANGER FIELD VOLTAGE
39 V DC
MANUAL
AUTO

FIGURE 18 : MARTINDALE TS/FC
CIRCUIT K1Z O/S, MARTINDALE FC1 & FC7 I/S, EFFECT OF PLACING FC1 25 Hz VOLTAGE REGULATOR O/S